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EARTH, SAND-CLAY, AND GRAVEL ROADS

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CONTENTS.

	Page.		Page.
Location and design	2	Gravel roads	45
Earth roads	15	Road maintenance	58
Sand-clay roads	34	Appendix: Typical specifications	63

According to recent statistics gathered by the Office of Public Roads and Rural Engineering, the aggregate length of all public roads in the United States is, roughly, two and one-half millions of miles. Of this total mileage, earth roads comprise about 89½ per cent, or considerably more than 2,200,000 miles; sand-clay nearly 2 per cent, or 44,000 miles; and gravel about 4½ per cent, or 116,000 miles, which leaves only about 4 per cent, or about 110,000 miles, for all other types combined. The statistics also show that in the 10 years from 1904 to 1914 the increase in the mileage of improved roads, other than earth, sand-clay, and gravel, has been only from 2 to 3 per cent of the total, and that in States having the greatest mileage of improved roads, only about one-half of their aggregate mileage has yet been improved. From these figures it is evident that the construction and maintenance of earth roads will continue to be of considerable importance in connection with every comprehensive plan of public road improvement. Also, since sand-clay and gravel surfaces often constitute the first steps from earth roads toward the more highly improved surfaces, either one or both of these simple types may be expected to constitute in the future, as at present, no small part of the total improved mileage in practically every community. On account of this wide distribution of earth roads and their close relationship to sand-clay and gravel surfaces, public interest in these three types is both genuine and general and gives ample warrant for

the issuance of this bulletin, the aim of which is to supply reliable information concerning the construction and maintenance of earth, sand-clay, and gravel roads.

LOCATION AND DESIGN.[1]

Since nearly all public roads are laid out originally as earth roads, and since the original location and design usually have such an important bearing on all subsequent improvements, it seems well to include in this bulletin a brief discussion of the fundamental principles underlying the proper location and design of a public road. But, before undertaking such a discussion in detail, it is desired to emphasize the all-important facts that for a particular road the best and most economical location depends largely upon individual judgment, and that well-balanced and experienced judgment regarding the relative importance of the various details involved is a much more valuable asset in undertaking to locate a road than mere technical skill in handling surveying instruments. No knowledge gained from books alone can give that complete grasp of the relations existing between a public road and the community it serves which is so necessary if the location and design of the road are to secure the greatest possible good from the money expended.

In locating or relocating a public road the prime considerations should be, first, the comfort and convenience of the traveling public which it is intended to accommodate; and, second, the economy of public funds. The first consideration fixes the general location of the road and limits such details of design and layout as affect the safety and comfort of travelers. The second should control the detailed working out of a location to suit the topography or surface layout of the region through which the road passes, with due regard for such features of the design as affect the cost of construction, of maintenance, and of hauling over the completed road.

The comfort and convenience of travelers require, first, that the road pass conveniently close to the dwelling places of those for whose particular use it is built; second, that it be free from dangerous curves and grades and sufficiently wide for safe travel; and, third, that the surface be such as to remain reasonably firm and smooth and to become neither very dusty nor very muddy under any combination of weather and traffic conditions. The extent to which any particular road must meet these requirements depends, of course, on the state of public sentiment in the community which pays for the road. But in most communities it is safe to assume that the standards of excellence as regards the accommodation demanded of

[1] This section has been read and revised by P. St. J. Wilson, chief engineer, and T. Warren Allen, general inspector, U. S. Office of Public Roads and Rural Engineering.

public roads will be raised rather than lowered. Due foresight, therefore, should be exercised in working out the location and design of a road, so that later improvements, such as reducing grades, increasing the width of the traveled way, or constructing a better surface, can be made without the necessity of making expensive changes in the location or otherwise wasting any considerable part of the work already accomplished.

A few general rules regarding the location and design of public roads may be stated briefly as follows:

1. Avoid sharp curves in the road, because such curves are a menace to traffic. On light grades and level stretches the location should be preferably such that a traveler may see at least 200 or 300 feet ahead from any point on the road, and on steeper grades this distance should be increased if automobile traffic is to be reasonably safe. Where the view is unobstructed and the grade is practically level country roads of ordinary width may be curved to a radius of only about 200 feet without seriously inconveniencing traffic, but to safeguard against accidents the radius of curves located on grades should be preferably not less than about 300 or 400 feet, even if the view is perfectly open.

2. Provide ample width for vehicles to pass each other without leaving the traveled way. The question of proper width is discussed on page 11.

3. Bear in mind that if a road ever becomes of any considerable importance, its users probably will demand that all the steeper grades be reduced to the lowest maximum that would conform to the general topography of the region which the road traverses. The question of grades is discussed on page 11.

4. Avoid all unnecessary distance. Aside from the advantages to traffic of a short route, each mile of additional road involves a considerable extra yearly expense for maintenance, and this alone may warrant the extra expense of shortening the route when the road is constructed, provided that the decrease in distance does not materially increase the steepness of the grades.

5. Regard land lines only in so far as this may be done without decreasing the usefulness of the road or increasing its ultimate cost. The tendency in most rural communities is to locate all new roads along land lines, regardless of the suitability of the route, and this has been responsible for much waste in the past. Not infrequently roads located along land lines have been graded at considerable expense, and abandoned later when the community demanded a more highly improved road with better grades.

6. Give reasonable consideration to the pleasing features of the location. A large part of the travel on most country roads is for

pleasure, and the degree of pleasure experienced in driving is largely dependent upon the scenic attractiveness of the road.

7. Plan to avoid the necessity for subsequent changes in location. Such changes nearly always work hardship on some of those who have built homes along the road.

The actual procedure of laying out a road should be controlled very largely by the lay of the land which the road is to traverse. Where the country is comparatively level, for example, practically the whole problem, aside from proper drainage, may be to determine a reasonable balance between the desire to avoid unnecessary damage to farming land and the purpose to secure a reasonably direct route over good ground.

One of the most common problems in laying out a road in level country is to decide between continuing a circuitous route around cultivated fields or along rectangular land lines, and estabishing a new diagonal route across the fields. Tables 1 and 2, showing, respectively, the area in acres occupied per mile by roadways of various width, with other relevant data, and the diagonal distances across rectangles of various lengths and breadths may be of some assistance in these cases.

TABLE 1.—*Areas occupied by roadways of various widths and cubic yards of surfacing material required for 1 inch loose depth.*

Width of roadway in feet.	Area in acres per mile of length.	Area in square yards per mile of length.	Cubic yards of surfacing material required for each 1 inch loose depth per mile of length.	Width of roadway in feet.	Area in acres per mile of length.	Area in square yards per mile of length.	Cubic yards of surfacing material required for each 1 inch loose depth per mile of length.
8	0.97	4,693.3	130.3	30	3.63	17,599.9	488.7
10	1.21	5,866.6	162.9	36	4.35	21,120.0	.....
12	1.45	7,040.0	195.5	40	4.84	23,466.4	.....
16	1.93	9,386.6	260.6	50	6.05	29,333.3	.....
20	2.42	11,733.3	325.8	60	7.26	35,199.6	.....
24	2.90	14,080.0	390.9				

TABLE 2.—*Lengths of diagonals in miles for rectangles of various lengths and breadths.*

Length of rectangle.	Breadth of rectangles.							
	¼ mile.	½ mile.	¾ mile.	1 mile.	1¼ miles.	1½ miles.	1¾ miles.	2 miles.
¼ mile	0.353	0.559	0.790	1.031	1.274	1.520	1.767	2.015
½ mile	.559	.707	.901	1.118	1.346	1.581	1.820	2.061
¾ mile	.789	.901	1.060	1.251	1.457	1.677	1.904	2.135
1 mile	1.037	1.118	1.250	1.416	1.607	1.802	2.015	2.236
1¼ miles	1.274	1.346	1.459	1.600	1.767	1.952	2.150	2.358
1½ miles	1.520	1.581	1.676	1.802	1.952	2.121	2.304	2.500
1¾ miles	1.768	1.820	1.904	2.015	2.150	2.304	2.475	2.657
2 miles	2.015	2.061	2.136	2.236	2.356	2.500	2.657	2.828

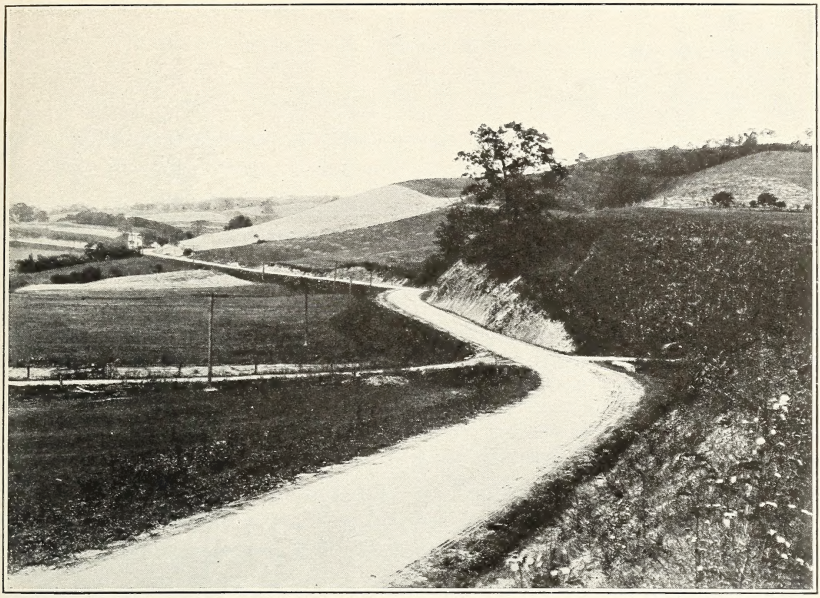

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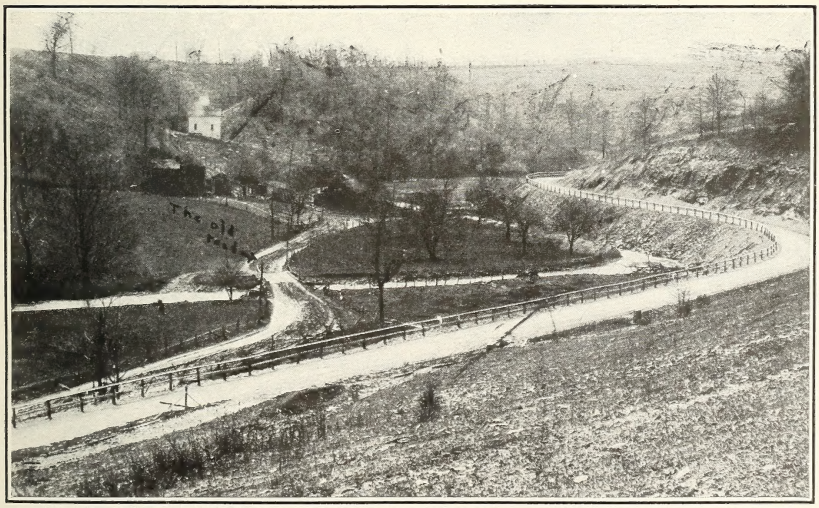
FIG. 1.—LOCATION OF ROAD FITTED TO GROUND SURFACE.



OPRRE3304

FIG. 2.—SHOWING WHERE RELOCATION WAS NECESSARY WHEN IT CAME TIME TO IMPROVE THE ROAD SURFACE. ALL WORK DONE IN GRADING THE OLD ROAD WAS ABANDONED.

In mountainous regions, on the other hand, the problem may be to fit the road to the contour of the country, regardless of land lines, cultivated fields, and all other considerations except grade, drainage, and line. Plate I, figures 1 and 2, illustrates methods of solving some common location problems where the lay of the land, or topography, was an essential consideration.

In general, the proper location and design of a road involves: (1) determining its controlling points; that is, fixing its general route with reference to certain points which the road must pass through, (2) surveying a route which passes through the controlling points and is otherwise adapted to the lay of the land, (3) a study of the drainage situation, (4) preparing such plans and drawings as are necessary for proper construction and a complete record.

CONTROLLING POINTS.

Such features of the locality as gaps through ridges, exposure to the sun, narrow stream crossings, and suitable points for crossing railroads (preferably by means of overhead bridges or under passes), together with the necessity for connecting up with certain centers of population, usually will serve to fix the location of a road within fairly definite limits. For important roads these controlling points are determined by careful inspection of all possible routes.

THE SURVEY.

The care which should be exercised in making a road survey necessarily must depend upon the importance of the road and the amount to be expended in its improvement. An ordinary farm road, for example, usually requires no survey other than lining it by the eye between the controlling points. Some unimportant public roads may require very little more than farm roads in the way of a survey, but if any considerable amount of grading or other work is to be done, either at the time the road is located or later, the survey should include all instrument work necessary to insure that the work will be done economically.

The purposes of a survey are (1) to determine accurately the topography or lay of the land so that the location may follow the route which presents the fewest obstacles, (2) to fit the grade line to the ground surface so as to keep down the amount of grading necessary, (3) to balance cuts and fills so that whatever grading is done will be to the best possible advantage, (4) to line up the road and provide stakes for controlling the work, (5) to obtain data from which proper plans may be prepared and an estimate of cost made, (6) to provide a record that will prevent subsequent contentions among landowners regarding the original location of the road. While the importance of all these purposes is apparent, frequently it

is not realized that they can not be accomplished except by means of a careful survey, and that such surveys can be made only by experienced men who have been trained especially for such work. Farmers and business men generally are inclined to underestimate the amount of skill required to make a road survey properly and their influence has been responsible in the past for much bungling and for uneconomical road work for which they have had to pay in heavy taxes.

Figure 1 illustrates an error which is made sometimes by inexperienced persons in grading a road without first having surveyed and planned the work. In this figure, which is an actual profile of an existing road, line A shows the original ground surface, line B shows the grade to which the road was actually constructed, and the dotted line (C) shows a grade line which, if it had been followed, not only

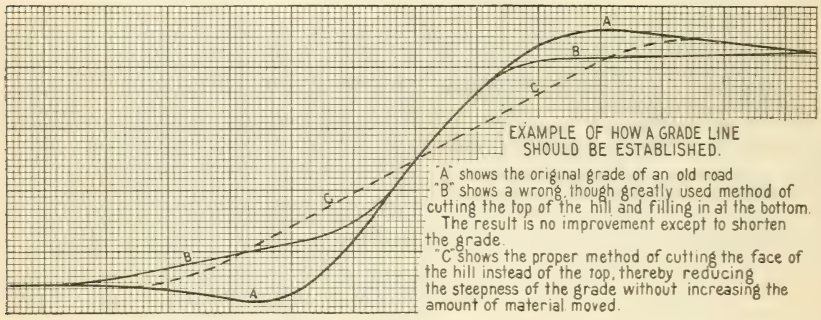

A
B
C
EXAMPLE OF HOW A GRADE LINE SHOULD BE ESTABLISHED.
"A" shows the original grade of an old road
"B" shows a wrong, though greatly used method of cutting the top of the hill and filling in at the bottom. The result is no improvement except to shorten the grade.
"C" shows the proper method of cutting the face of the hill instead of the top, thereby reducing the steepness of the grade without increasing the amount of material moved.

FIG. 1.

would have required no additional work, but would have reduced the steep grade materially and thereby improved the road considerably.

In fitting the grade line to the ground surface and balancing cuts and fills it should be borne in mind that earth, after being thoroughly compacted, will occupy less space in an embankment or fill than in its original position. The customary allowances for shrinkage and waste in road work are:

	Per cent.
For heavy cuts and fills	10 to 15
For average grading	15 to 20
For light grading	20 to 30
For very light grading and considerable sod	30 to 40

Solid rock will expand from one-third to one-half of its original volume when taken from a cut or excavation and placed in an embankment. But the spaces between the particles of stone should be filled with earth as the stone is being placed in the embankment. If this is done, no allowance should be made for the increase in volume when balancing cuts and fills.

DRAINAGE.

The subject of road drainage has been discussed at considerable length in other bulletins of the Office of Public Roads and Rural Engineering, and therefore will be given only brief mention here.

Effective drainage usually should be the very first consideration in connection with the location and design of any road. This statement requires no explanation, because the action of water in changing clay into mud and in causing all kinds of soils, except sand, to give way when a load is applied, is familiar to every person living in

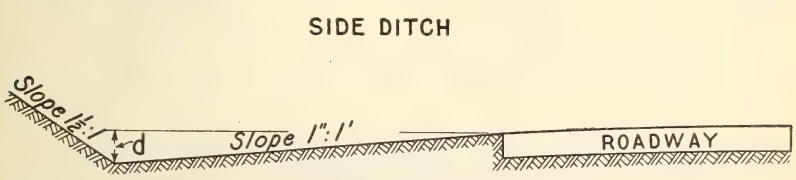


FIG. 2.

a humid climate. The following summary supplies a few suggestions as to how water may best be removed from a road bed:

1. The road surface should be crowned so as to shed water off to the side ditches as rapidly as it falls on the road. The typical cross sections (shown in figs. 15, 20, and 22) indicate the amounts of crown advisable under different conditions. These figures are supplemented by a discussion on page 9.

2. Wherever the road is in an excavation, suitable side ditches or gutters should be provided along the sides so that the water may

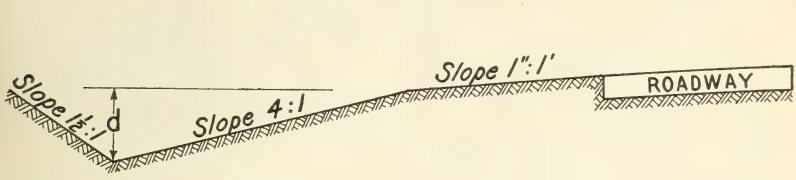


FIG. 3.

be conducted to some point where it may be turned off from the road. Figures 2, 3, and 4 show typical cross sections for earth side ditches. The cross section shown in figure 2 is suitable for steep grades where the depth of water in the side ditches must be kept low in order to prevent washing of the soil. Figure 3 shows a modified section which gives a greater capacity for the same widths of ditch than the cross section shown in figure 2, but which can be employed only on comparatively flat grades if washing is to be prevented. Figure 4 shows a cross section adapted especially to flat grades where a considerable volume of water must be carried. Ditches of the

cross sections shown in figures 2 and 3 have the advantage in that they may be constructed with an ordinary road grader, which is not true of the section shown in figure 4.

3. Where it is impracticable to construct side ditches that will carry the required amount of water without washing, paved gutters should

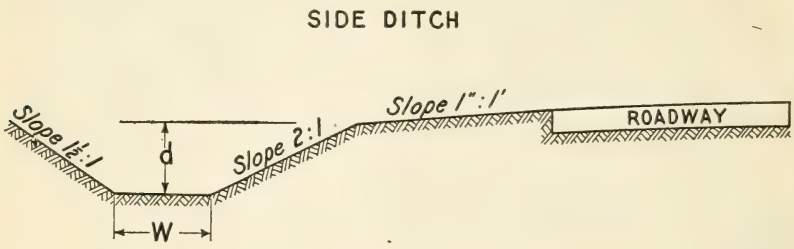


FIG. 4.

be employed. Suitable cross sections for a cobble gutter are shown in figures 5 and 6. Where it is impracticable to construct gutters, earth side ditches frequently may be kept from washing by the use of breakers (figure 7).

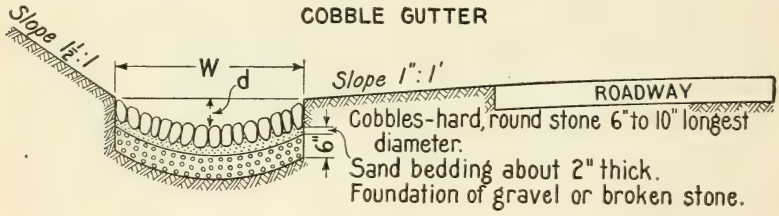


FIG. 5.

4. If the material composing the roadbed consists of springy earth, some form of underdrainage is essential. A line of farm tile laid to proper grade under each side ditch is, in general, the most satisfactory way of securing adequate underdrainage. Either 4-inch

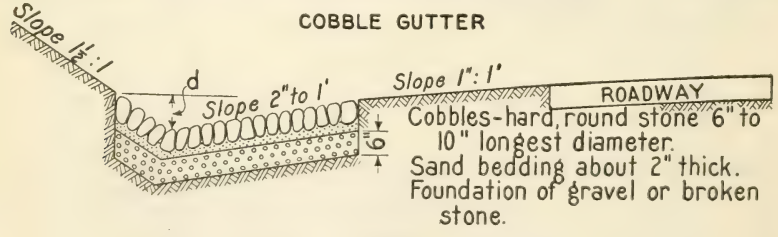


FIG. 6.

or 6-inch tile is employed for this purpose. Figure 8 illustrates the customary method of constructing tile drains.

5. Culverts or bridges should be constructed wherever it is necessary to carry water across the road. No rules regarding the planning of these structures can be given here.

6. Avoid turning water from one intersecting road down the side ditches of another. Also avoid draining adjacent fields into the side ditches.

CROWN.

The proper crown to give the cross section of a road surface depends on two opposed factors:

(*a*) It is desirable to get water away from the surface as quickly as practicable, so as to prevent the surface material from being softened by saturation or washed away by water collecting in, and flowing along, ruts.

(*b*) It is desirable to keep the cross section of the road as flat as is consistent with good drainage, because traffic distributes itself over a flat road surface much better than over one that is heavily crowned, and an even distribution of traffic makes toward uniform wear and comparatively light maintenance. There is also less danger of skidding on a road of flat cross section than where the surface is crowned.

OPRRE12252

FIG. 7.—Use of wooden breakers to prevent scour of side ditch.

In general, the amount of crown should be greater on grades than on level stretches of road, because the tendency for water to wash away the surface by collecting in and flowing along ruts depends largely upon the steepness of the grade. Also the care with which a road is to be maintained may have an important influence on the amount of crown that should be given to the surface. It is evident that a road surface maintained in a smooth uniform condition will shed water off to the side ditches with much less crown than would be required where ruts are allowed to form.

Instead of crowning the road surface sufficiently to prevent water from flowing along the traveled way and causing washes on steep grades, resort is sometimes had to "water breaks," or "thank-you-ma'ams," constructed across the road at short intervals. These water breaks may consist of either broad, shallow ditches or flat ridges constructed at a slight angle with the road so as to turn

water from the traveled way into the side ditches. Such devices usually are much more objectionable, especially to automobile traffic, than a rather heavily crowned road, provided the surface is not constructed of material which becomes very slippery when wet, and they should be dispensed with except in extreme cases.

An exception to the general rules for crowning a road surface perhaps should be noted as applying to cases where the roadbed and surface are of sand. In such cases it is preferable that the cross section be flat so as to retain as much moisture as practicable, though in cold climates a slight crown may be desirable in order to afford drainage when the surface is frozen. But sand roads must be surfaced with some other material if they are to be improved to any extent, and in that case the surface of the traveled way would have to be crowned as usual. Also, where curves occur in the alignment it is desirable to "bank" or elevate the outer edge of the roadway and thus make the crown one way.

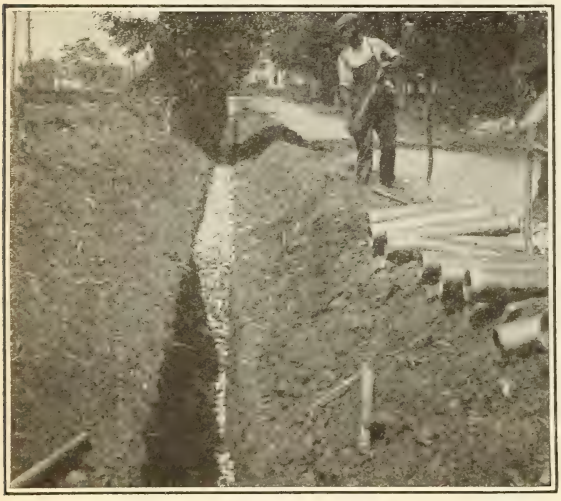


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FIG. 8.—Constructing a tile drain, Montgomery County, Md.

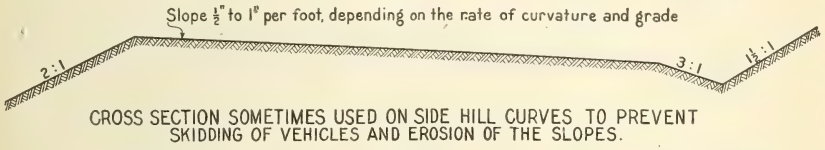
Bearing in mind the foregoing discussion, the crown limits indicated for the typical cross sections (shown in figs. 15, 20, and 22, respectively), should prove a fairly reliable guide in determining the proper crown for earth, sand-clay, and gravel road surfaces under any set of conditions ordinarily encountered.

Figure 9 shows a cross section sometimes used for roads cut into side hills. The advantages claimed for this section are that whatever skidding occurs will be toward the hill rather than over the bank, and that the drainage water collected in the side ditch can be turned across the road at suitable points instead of being allowed to wash away the face of the embankment and perhaps damage abutting property. Except where short curves occur in the road, these advantages hardly seem sufficient to overcome the objection that all water falling on the upper portion of the surface must flow across the lower portion in order to reach the side ditch. Traffic naturally will seek the part of the road next to the hill, and this concentration of traffic, together with the additional water, will tend to produce mud.

WIDTH.

The minimum width to accommodate safely two lines of average horse-drawn traffic is 14 feet, and for automobile traffic the width preferably should be not less than 18 feet, though a width of 16 feet is used frequently. In order to maintain the traveled way to the required width and to afford proper safeguards against accidents, it is necessary to provide a shoulder not less than 3 or 4 feet wide along each side of the roadway proper. The shoulders may have a somewhat steeper crown than the rest of the road surface, as shown on the cross-section drawings, figures 21 and 22, but they should be sufficiently flat not to endanger traffic using them and really should constitute an additional width of roadway. This means that the total width of roadway between side ditches never should be less than 20 feet where horse-drawn traffic predominates, and 24 feet where any considerable volume of automobile traffic is to be accommodated.

Where sharp curves occur in the alignment it is desirable, though not customary, to increase the width of the traveled way. A vehicle being drawn along a curved road tends to occupy an appreciably greater width than where the road is straight, and unless the width



CROSS SECTION SOMETIMES USED ON SIDE HILL CURVES TO PREVENT SKIDDING OF VEHICLES AND EROSION OF THE SLOPES.

FIG. 9.

of the traveled way is increased correspondingly, this tendency contributes materially to the hazards that invariably accompany sharp curves. The minimum widths given above should also be increased on embankments of any considerable depth, so as to make maintenance easier and at the same time diminish the danger of accidents.

The width of right of way required to provide all necessary area for the roadway, slopes and ditches varies considerably with the nature of the topography. Where the topography is flat, or gently rolling, a 50-foot right of way usually will be sufficient for a 20-foot roadway. But where the country is very rolling or hilly the width of right of way usually should be at least 60 feet. For roadways wider than 20 feet it is usually sufficient to increase the width of right of way by the same amount that the width of roadway is increased.

GRADES.[1]

In designing a public road one of the most difficult problems to solve properly is the question of maximum allowable grades. In

[1] E. B. McCormick, mechanical engineer, U. S. Office of Public Roads and Rural Engineering, has furnished the data on which this discussion is based.

deciding this question, the advantages to be gained by reducing all of the steeper grades on a particular road to a given maximum should be weighed against the additional cost which the reduction involves.

The following data and suggestions are intended to aid individual judgment, which necessarily must be the prime factor in solving this important problem:

1. The cost of average pleasure traffic, horse-drawn and motor, is practically unaffected by grades of not more than 6 or 7 per cent (6 or 7 feet rise per 100 feet, measured horizontally), provided the conditions are such that it is unnecessary to apply the brakes to vehicles when descending the grades. But for traffic where loads are as important as speed, even very light grades may be of considerable disadvantage.

2. Increasing the steepness of a grade decreases in three distinct ways the load a horse can haul: (*a*) for the same character of surface, the required tractive effort or pull[1] per ton of load is increased by about 20 pounds for each per cent increase in grade; (*b*) the possible pull the horse can exert is decreased by an amount equal to the effort required to lift his own weight through the rise; this amount is approximately equal to one one-hundredth of the horse's weight for each per cent increase in grade; (*c*) the effective pull of the horse is reduced by the change in the angle at which the pull is applied.

3. The pull a horse can exert on a level road varies greatly with the individual animal, and is affected by the manner of hitching and the skill of the driver. The character of the road surface also may have an important influence by affecting the security of the horse's foothold.

Tests[2] made by the Office of Public Roads and Rural Engineering indicate that, on a level road, average farm horses untrained to the road can exert a steady pull for several consecutive hours equivalent to from 0.08 to 0.10 of their own weight without undue fatigue, and that by resting at intervals of from 500 to 600 feet they can exert a pull equivalent to about 0.25 of their weight, provided the foothold is good.

4. The tests referred to above also indicate that with a well-constructed wagon the pull required to move a gross load of 1 ton over a level road varies about as follows:

	Pounds.
Loose sand road	315
Average dry earth road (varies greatly)	150
Firm earth or sand-clay road	105
Average gravel road	80
First-class gravel or macadam road	55

[1] Pull is here used to mean the actual strain which a horse exerts against the whiffletree, and which might be measured by placing steelyards in the traces.

[2] These tests are not yet complete and subsequent results may cause the conclusions to be slightly modified.

5. Table 3 of loads is based on the foregoing statements, assuming the weight of the average horse at 1,200 pounds, the pull he is capable of exerting continuously for several consecutive hours on a level road at one-tenth of his weight, his maximum pull on a level road, over a distance not to exceed 500 feet without a rest, at twenty-five one-hundredths of his weight; and assuming that a proportionate part of a horse's energy is devoted to lifting his own weight on grades.

TABLE 3.—*Effect of grades on the gross load a 1,200-pound horse can haul.*[1]

Per cent of grade.	Road through deep sand.		Road over average dry earth.		Road over firm earth or sand-clay.		Average gravel road.		First-class gravel or macadam road.	
	Continuous load.	Maximum load.	Continuous load.	Maximum load.	Continuous load.	Maximum load.	Continuous load.	Maximum load.	Continuous load.	Maximum load.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
0	760	1,905	1,600	4,000	2,285	5,715	3,000	7,500	4,365	10,910
1	645	1,720	1,270	3,390	1,725	4,610	2,160	5,760	2,880	7,680
2	540	1,550	1,010	2,905	1,325	3,805	1,600	4,600	2,020	5,810
3	445	1,410	800	2,515	1,020	3,200	1,200	3,770	1,460	4,590
4	365	1,275	625	2,190	780	2,725	900	3,150	1,065	3,735
5	290	1,155	480	1,920	585	2,340	665	2,665	775	3,100
7	160	950	250	1,490	295	1,765	330	1,965	370	2,215
10	.....	700	.....	1,030	.....	1,180	.....	1,285	.....	1,410
15	.....	390	.....	535	.....	590	.....	630	.....	675

[1] This table is based upon the assumption that for the same road surface the pull varies directly with the weight of the load. Tests to be made may make it necessary to modify this assumption.

Table 3 shows conclusively that for economy the maximum grade for any particular road should be fixed with due regard for the type of surface to be employed. For example, where the road is through deep sand, a horse of the character assumed, by extraordinary exertion, could pull his allowable continuous load of 760 pounds for level grades up a short grade of about 10 per cent, while in the case of a firm earth or sand-clay road the allowable continuous load for level grades is 2,285 pounds, and the steepest grade up which the horse could possibly pull this load is about 5 per cent. For average gravel roads the corresponding comparison would show a maximum grade of about 4 per cent.

Comparisons of the kind made in the preceding paragraph are not sufficient, of course, to determine the maximum allowable grades for any particular road, because, in general, the judgment should be largely influenced, in fixing the maximum grade, by the topography of the region which the road traverses. According to the best current practice, where the road is or is expected to become of sufficient importance to warrant a highly improved surface, the maximum grade usually is fixed with reference to this feature about as follows:

	Per cent.
Coastal plain and prairie regions	2 to 3
Average rolling country	4 to 6
Hilly or mountainous regions	6 to 8

*

The question of minimum grade is of importance only as regards the side ditches. These should have adequate fall to empty the water that collects in them at a sufficiently rapid rate to prevent damage to the road. Ordinarily it is desirable to give the side ditches a fall of about 1 foot per 100 feet of length, though a somewhat less fall has proved satisfactory sometimes.

Wherever changes in grade occur the change should be made by means of a vertical curve, and not by an abrupt angle.

SLOPES.

The slope at which earth will stand when faced up in a cut or placed in an embankment depends (1) on the character of the earth and (2) on the climate. In cuts, a good quality of nonslaking clay often will stand on a slope of about 45 degrees, or, as slope is expressed usually, 1 horizontal to 1 vertical, even where fairly deep freezing occurs, and in some of the Southern States such material has been known to stand for many years on a slope of less than one-half to 1. On the other hand, clay that slakes very easily may require a slope of 3 to 1, or even 4 to 1, under the most favorable condition of climate, but this latter extreme is very unusual. The usual slope for clay in cuts is 1 to 1 in warm climates and 1½ to 1 in cold climates.

While in the case of embankments clay usually can be deposited on an initial slope of about 1 to 1, this steep slope seldom can be maintained unless the material is of an exceptional quality and the climate very favorable. Ordinarily clay embankments should have a slope of about 2 to 1 in cold climates and at least 1½ to 1 in warm climates; and if the clay be of questionable quality these values should be increased. Embankment slopes require more care in construction than excavation slopes, because any flattening of an embankment slope by the action of weather after the road is completed is very likely to damage the road surface, while the sliding in of excavation slopes does no further damage than to obstruct the side ditches, which can be reopened readily.

Sand of average quality generally requires a slope of about 2 to 1 in cuts and 3 to 1 in embankments, regardless of climate. Moderately coarse sand mixed with gravel will stand on a steeper slope than fine sand, because the former is not moved so readily by the action of storm water.

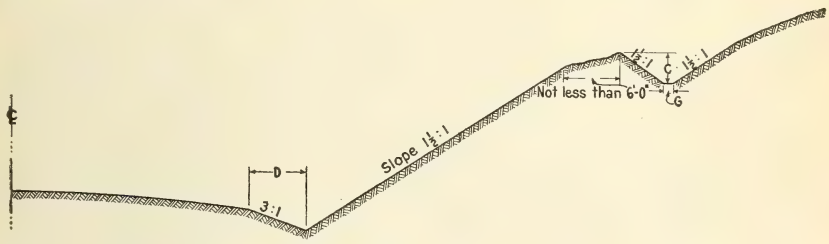
Solid rock excavation usually can be done on an average slope of about one-fourth to 1, except where the rock occurs in sloping strata separated by slippery clay seams. In the latter case the average slope may be as much as one-half to 1 or three-fourths to 1. The faces of rock cuts, as a rule, are not dressed down to even an

approximately smooth slope, as is done in earth cuts. In excavating solid rock only such material is moved as is actually necessary to obtain the desired width at the bottom of the cut or as has been loosened in blasting. The faces should, of course, be cleared of all material which is loose, or which might be loosened subsequently by frost and slide down upon the road. Stone embankments will stand on a slope of about 1 to 1.

In order to prevent damage by washing all earth slopes in either excavation or embankment should be protected by a growth of grass as soon as practicable after they are formed.

In many localities where the soil is fertile and a good quality of grass is native no seeding of the slopes is necessary. In other cases the soil may not possess sufficient fertility to grow grass, even when the slopes are seeded, and in which event it may be very desirable to cover the slopes with cut sod. This latter process usually is very expensive, and should be employed only where it is known that thorough seeding and fertilizing would fail to secure a covering of sod.

Another precaution frequently necessary in order to prevent the washing away of excavation slopes is to intercept water from the



CROSS SECTION SHOWING BERM DITCH BUILT ABOVE SLOPE

Dimensions of the ditch are determined by the amount of water to be carried. "C" is generally 18" to 24" and "G" about 12".

FIG. 10.

natural ground surface which otherwise would flow down over the excavation slope. This is done by means of a "berm" ditch constructed well back from the top of the slope. Figure 10 illustrates a condition which makes a "berm" ditch desirable and also shows how such a ditch is constructed.

EARTH ROADS.[1]

Roads constructed by grading the natural soil to the required shape, grade, and alignment, without special surfacing of any kind, are designated as earth, or dirt, roads. The efficiency of such roads

[1] This section has been read and revised by P. St. J. Wilson, chief engineer, and T. Warren Allen, general inspector, U. S. Office of Public Roads and Rural Engineering.

depends (1) on the quality of the soil composing the roadbed, (2) on proper construction, and (3) on adequate maintenance.[1]

SOILS.

The principal qualities of soils from the standpoint of road construction depend upon texture and structure, permeability, and capillary power. Soils usually are classified as clay, sand, loam, gravel, marl, or gumbo, according to the material predominating in their composition. Soils composed of two different materials mixed in such proportions that the character of the mixture is decidedly intermediate may be designated conveniently by naming both components, as sand-clay, sand-gumbo, gravelly clay, etc. Reference to Table 4, giving approximate bearing powers for different soils, will show that this classification may be of considerable significance in road construction.

TABLE 4.—*Approximate safe bearing powers for different soils.*

Kind of soil.	Range of bearing power (pounds per square inch).	Kind of soil.	Range of bearing power (pounds per square inch).
Dry clay	50 to 80.	Moist loam	3 to 10.
Moist clay	6 to 50.	Dry gumbo	15 to 30.
Sand or gravel	25 to 85.	Wet gumbo	1 to 10.
Dry loam	10 to 20.	Marl	Same as clay.

CLAY.

Clay is a soil of very fine texture which results from the complete decomposition of rocks or minerals. Pure clay is very retentive of moisture and usually becomes plastic and unstable when wet, but when mixed with other materials, such as sand or gravel, its stability may be increased greatly. In general, a clay road, to be passable, must be kept dry, and since clay is very difficult to drain, it happens seldom that roads composed entirely of clay can be kept in good condition at all seasons of the year. No matter how well such a road may be graded and crowned the surface absorbs water in wet seasons and subsequent traffic will produce mud. But when the road is shaped and drained properly it will dry out quickly when the weather becomes favorable and may soon be restored to its original shape. On the other hand, clay roads, when very dry, usually produce considerable dust under traffic, and for this reason may become very insanitary in extended dry seasons.

The extent to which clay roads are subject to the objections mentioned above varies generally according to the so-called "slaking"

[1] Since the discussion of maintenance, as treated in this bulletin, will apply to the three road types under consideration, it has been placed after the chapter on gravel road construction.

qualities of the clay. Some varieties of clay, when compressed into a ball and placed in water, will continue in the original shape for a considerable time, even if thoroughly saturated and softened, while compressed balls made from other varieties will slake or break down almost immediately upon being placed in water. Clays of the first-mentioned variety are called "nonslaking clays," and of the latter, "slaking clays." It has been observed that slaking clays produce more mud in wet weather and more dust in dry weather than those of the nonslaking variety. This characteristic of clays is further considered in the discussion of sand-clay roads appearing in another part of this bulletin, where methods for testing clay are suggested.

Most clays, as they occur in nature, contain more or less sand or gravel, which, as pointed out above, usually has a stabilizing effect by making the clay more easily drained and increasing its bearing power when wet. In fact, a good quality of clay mixed with coarse sand in such proportions that the clay fills the voids in the sand and cements the individual particles together produces a soil which possesses the good qualities of both materials and which overcomes, to a great extent, the objections to each.

SAND.

Sand is composed of granular particles of mineral or stone which occur in nature and which will pass a ¼-inch mesh screen. The ¼-inch mesh screen is fixed arbitrarily as the dividing line between sand and gravel and is generally, though not universally, accepted as such. Nearly all sand consists essentially of quartz grains that are very hard and durable. But there is no coherence between the different grains, and therefore soils composed principally of sand are unstable, except when confined in some way. If properly confined and protected from undermining, sand foundations may, under favorable climatic conditions, prove entirely satisfactory for almost any type of road crust, but it is practically impossible, under any circumstances, to make a satisfactory road surface of sand alone. Dry sand offers almost as great resistance to traffic as mud, and except in very wet seasons sandy roads are likely to dry out to a considerable depth. The reason for this is that the capillary power of sand is comparatively low and the ground-water elevation may be lowered practically to the prevailing level of surface streams in extended dry seasons.

Sand roads are at their best when they are kept moist, and for this reason they should be designed with a view to retaining moisture in the sand rather than to effective drainage, as is the case with clay

roads. Such roads sometimes are improved temporarily by mixing sawdust, straw, pine leaves, or other similar material into the surface, but, in general, the sand-clay crust is the most satisfactory improvement for roads of this character. This is true especially where clay may be obtained readily and only limited funds are available for the improvement.

LOAM.

Loam is a soil composed of clay and sand, mixed with a considerable percentage of finely divided vegetable matter or humus. The quality of loam from the standpoint of road building depends very largely upon the proportions in which sand and clay are present and on the character of these materials. Loam that contains about 60 per cent of moderately coarse sand and from 20 to 30 per cent of good cementing clay usually will make an excellent road surface for light traffic. Material of this kind is drained easily and is fairly stable, even when wet. Another advantage is that it will not become very dusty under traffic in dry weather and frequently will cement together into a very hard, compact surface. Roads surfaced with such material are commonly called "topsoil" roads, because the topsoil of cultivated fields possesses the desired characteristics more frequently than that to be obtained from any other source. Topsoil is considered further in this bulletin in connection with the discussion of sand-clay roads.

GRAVEL.

Gravel is made up of small rounded particles of stone which occur in nature and are sufficiently large to be retained on a $\frac{1}{4}$-inch mesh screen. Gravelly soils are distributed widely in the United States, and vary widely in quality. In general, when a soil contains as much as 40 or 50 per cent of gravel and sufficient clay or other cementing material to bond the gravel particles together, it proves a very satisfactory material for construction of roads, because it is drained easily and is very stable when compacted. The various characteristics of gravel are considered at much greater length in the discussion of gravel roads.

MARL.

Marl is clay containing a relatively large percentage of carbonate of lime. It grades into calcareous clay and argillaceous limestone, and its value for road building is variable. In general, this material has few advantages over the best varieties of ordinary clay for use in constructing a road, unless the percentage of lime carbonate is sufficiently high to give it, when compacted, approximately the character of limestone. The best varieties of marl become very hard

and compact when placed in a road surface, and in some localities this material is used extensively for road surfacing.

GUMBO.

Gumbo is essentially loam containing a high percentage each of clay and decayed vegetable matter and a very low percentage of sand. Gumbo has a strong tendency to absorb and hold water, and therefore is hard to drain. It is harder to handle in a road surface than clay, because the vegetable matter is an added weakness, but if protected from surface water by a proper system of drainage, it may be used to construct a fair subgrade for supporting some type of impervious road crust. Gumbo has a relatively high capillary power, and for this reason its occurrence in a road bed often will necessitate the use of subdrainage, even under conditions favorable for surface drainage.

CONSTRUCTION OF EARTH ROADS.

The work of constructing an earth road, after the general location and design have been decided upon, may be separated into six more or less distinct operations, viz:

(1) The work is staked out in accordance with previously prepared plans; (2) the right of way is cleared of all trees, brush, stumps, etc., which would interfere in any way with the work; (3) all necessary bridges, culverts, drains, and other structures which extend under the road surface are constructed in accordance with proper designs; (4) the roadbed is brought to the required width and grade by making excavations and constructing embankments; (5) the surface is finished to the required cross section and so maintained until compacted thoroughly; (6) all necessary outlet ditches, gutters, guard rails, fences, etc., are constructed in accordance with the plans.

STAKING OUT THE WORK.

Before any construction work is started on a road the limits of the work should be marked clearly by setting line and grade stakes at convenient intervals. The same stakes generally are made to serve for both line and grade, and the space between successive stakes is made 100 feet. Heavy reference stakes are driven on each side of the center line sufficiently far out not to be disturbed during the progress of the work. Then, as the work proceeds, such supplementary stakes as are necessary for marking the tops and bottoms of slopes, ditch lines, etc., may be set from the reference stakes by means of a string level and a metallic tape.

Culvert locations usually are fixed on the ground by means of two stakes in the line of the culvert, one near each end.

CLEARING.

After the work has been staked out the right of way should be cleared of all trees, stumps, brush, fences, etc., which occur within the lines of the work. Trees and stumps should be grubbed out or cut off at least 18 inches below the finished surface of the roadbed over them, and no parts of trees, stumps, or other perishable matter should be left in areas to be covered by embankments. Sightly trees that would not interfere with the work or obstruct the road in any way should be trimmed to a neat contour and left to afford shade.

CONSTRUCTING CULVERTS, DRAINS, ETC.

All drainage structures extending under the surface of the road should be completed, and the necessary backfills made over them before the work of grading is begun. There are two reasons for this. One is that usually less excavation will be required for such structures before the grading is completed than after, and the other that it is desirable to give the backfills as much time as possible to settle before the grading is completed, so as to avoid irregular settlement later.

The conditions under which culverts and drains are constructed vary to such a great extent that no attempt will be made here to discuss the detailed methods of construction.

GRADING.

The grading of an earth road includes all excavating, hauling, and filling necessary in constructing the roadbed, slopes, side ditches, etc., and usually is by far the largest item of work connected with earth-road construction. The most economical methods and machinery to employ in grading a particular road depend on the character and amount of the work to be done. Where, for example, the grade and cross section of the road follow closely the original ground surface most of the necessary grading usually may be done with a grading machine such as is illustrated in figure 11. In the case of embankments, built up with material from borrow pits along the sides of the road, an elevating grader (fig. 14) frequently may be used to advantage. If material must be moved longitudinally along the road from cuts to fills in order to bring the surface of the road to the required grade, the work usually must be done either with scrapers (figs. 16 and 17) or dump wagons (fig. 18). Where a considerable volume of material is to be excavated in a relatively short distance a small steam shovel (fig. 19) with dump-wagon equipment sometimes may be employed economically. Each of these methods may best be described separately.

USE OF GRADING MACHINE.

The grading machine illustrated in figure 11 is of the general design commonly followed in machines of this type. The heavy blade, which is 7 or 8 feet long and provided with a steel cutting edge, may be adjusted to any desired vertical or horizontal angle by means of hand wheels arranged conveniently about the operator's platform. Some of the best makes of grading machines are provided with attachments for such purposes as shifting the frame back and forth on the rear axle so as to adjust the blade to a desired position with reference to the wheel tracks, or to lean the wheels at an angle with the vertical and thus lessen the tendency of the machine to slide over a bank, or to

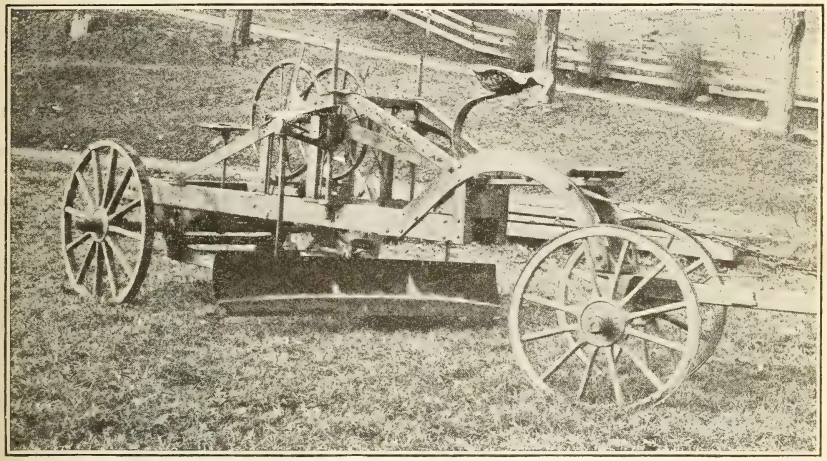


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FIG. 11.—Grading machine.

cut the rear wheels at an angle with the frame in order to overcome the tendency to slide when the blade is loaded. Most of the better makes of such machines are now constructed so the blade may be reversed entirely and the convex surface used for smoothing a road surface after it has been graded approximately to the required cross section. Machines of this type are made in different sizes and weights and cost from about $175 to $300 f. o. b. factory. The heavier sizes are best adapted for construction work and the lighter ones for maintenance.

A modified form of grading machine consists of a blade similar to that of the machine just described, which is supported by a simple frame on only two wheels. The 2-wheeled machine usually weighs only about one-fourth as much as the 4-wheeled type and costs considerably less, but the 4-wheeled type generally is to be preferred on account of its greater stability and also because it can be adjusted to meet a much wider range of conditions. In the following description

of the method of operation, therefore, it will be assumed that a 4-wheeled machine is to be used.

To operate a grading machine successfully where the work is moderately heavy requires at least six horses, while for light maintenance work after the road is graded four horses usually are sufficient. For satisfactory work the team must be accustomed to working together and must be under complete control of the driver. To break in a green team ordinarily requires two or three days of relatively very light work under favorable conditions and with a capable driver. Poorly trained teams and improper driving have been responsible for more unsatisfactory and uneconomical grading-machine work than any other one cause.

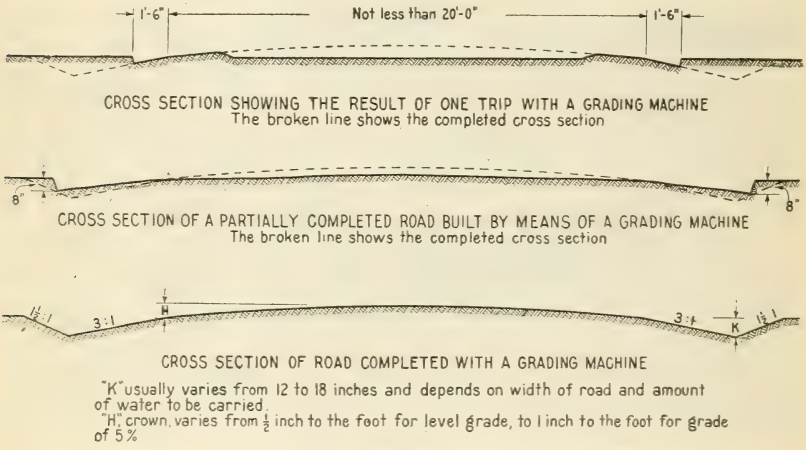

1'-6"
Not less than 20'-0"
1'-6"
CROSS SECTION SHOWING THE RESULT OF ONE TRIP WITH A GRADING MACHINE
The broken line shows the completed cross section
8"
8"
CROSS SECTION OF A PARTIALLY COMPLETED ROAD BUILT BY MEANS OF A GRADING MACHINE
The broken line shows the completed cross section
3:1
H
3:1
K
CROSS SECTION OF ROAD COMPLETED WITH A GRADING MACHINE
"K" usually varies from 12 to 18 inches and depends on width of road and amount of water to be carried.
"H" crown, varies from ½ inch to the foot for level grade, to 1 inch to the foot for grade of 5%

FIG. 12.

Before any machine work is done the area to be graded should be either burned or mowed over so as to remove all grass and weeds. The grading then should proceed as follows:

(1) Set a row of stakes, 100 or 200 feet apart, along the inside edge of each side ditch. The purpose of these stakes is simply to aid the driver in making the initial furrow of the machine conform with the line of the road, and since the stakes are destroyed by the first furrow they need be only sufficient to serve this temporary purpose. Figure 12 shows the successive steps involved in grading up a road with a grading machine after the ditch lines have been established as indicated.

(2) Set the blade of the grading machine at an angle of about 30 degrees with the road, so that the material loosened by the cutting point of the blade will be moved in toward the center of the road; also lower the cutting point and raise the heel, so that the blade will plow an initial furrow about 6 inches deep and about 18

inches wide. Then make the initial trip with the point of the blade cutting about 18 inches outside of the stake line and the outside rear wheel of the machine against the face of the furrow. The material loosened by the first furrow then will escape under the blade in a ridge just inside the stake line.

(3) Readjust the machine so that when the outside horses follow the initial furrow in making the second trip the blade will cut a new furrow of somewhat less width than the first and the outside rear wheel will follow the face of the new furrow. Then make successive trips with the machine adjusted in this way until the outside edge of the side ditch is approached, except that after each two trips it is well to rest the team by readjusting the blade and pushing the loosened material over toward the center of the road. For this latter work the blade may be set at a greater angle with the road, and the heel should be lowered and the point raised, so that the cutting edge will conform closely to the crown of the road while the machine is in operation.

(4) Repeat the above-described operation, omitting the stakes and beginning about 18 inches farther from the center each time, until the side ditches are excavated to the required depth and the road is approximately to the required cross section.

(5) Bring the outside faces of the side ditches to a uniform slope by making one or two trips of the machine with two wheels, one front and one rear, on the bank and the cutting edge of the blade against the slope.

(6) Make several trips over the road, cleaning out the ditches and smoothing up the surface. The last few trips should be made with the blade reversed, as this method tends to produce a better compacted surface. But, in any event, it is necessary that during the first few months after the grading is completed the road surface should be kept smooth while it is being compacted under traffic. To do this may require frequent use of the grading machine or the drag.

Plate II shows a model constructed by the Office of Public Roads and Rural Engineering for the purpose of illustrating in small space the successive steps involved in grading a road through level country by means of a grading machine.

The method of operating a grading machine described above necessarily will have to be modified at times in order to meet special conditions. Where, for example, the ditch area is covered with heavy sod or contains a number of large roots, it may be very desirable to plow this area and cut the roots with an ax before using the grading machine. If this is done the plow furrows should be turned toward the center of the road and the line of the initial furrows should be controlled by two rows of stakes as described above. If the sod is

very tenacious it should be harrowed with a disk harrow (fig. 13) ahead of the grading machine, and after the material has been moved over toward the center of the road the lumps of sod should be thrown out. A method sometimes followed is to skim off the sod, by means of hand shovels, ahead of the grading machine, but this method is expensive and seldom justified.

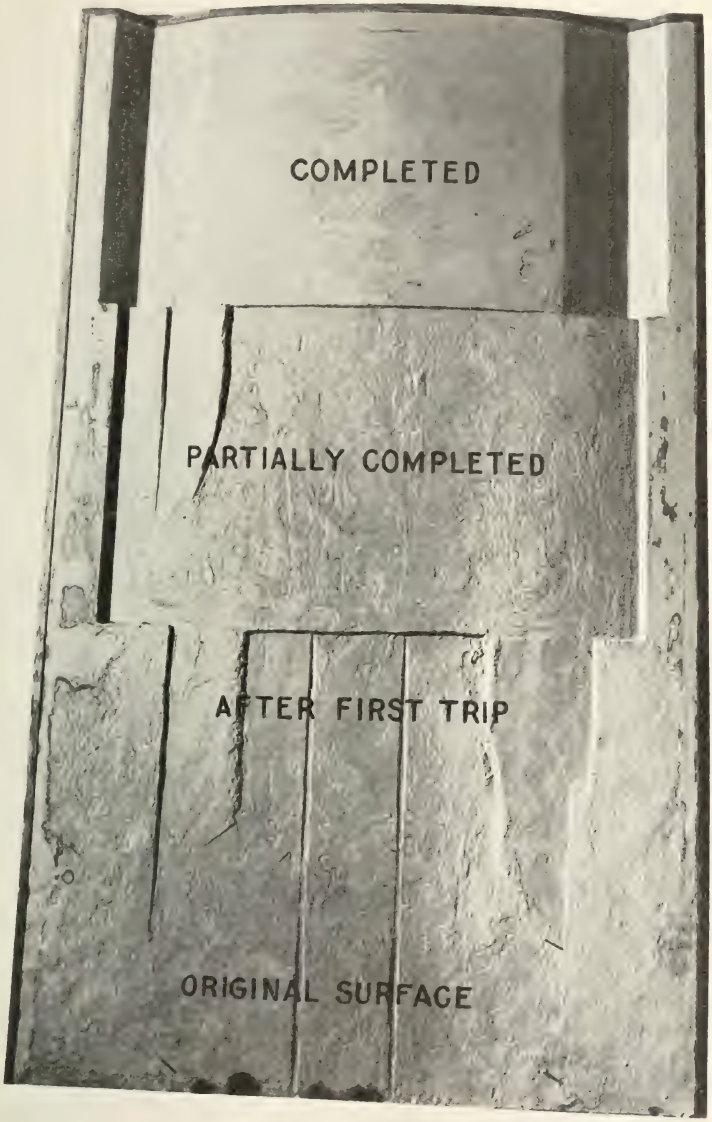
Whether or not it is necessary to contend with any considerable quantity of sod, the use of a disk harrow usually will prove helpful in securing a smooth uniform road surface with the grading machine. In general it is sufficient to give the loosened material a thorough harrowing after the road has been brought approximately to its required shape, but before the final shaping is done.

OPRRE733

FIG. 13.—Breaking up clods with a disk harrow.

Where continuous long stretches of road are to be graded with grading machines, it frequently is economical to substitute a traction engine for the teams and to employ two machines. Where this is done the first machine is connected immediately behind the tractor, either directly behind or to one side, as the conditions require, and the second machine is connected behind and to one side of the first. Otherwise the method of operation is not essentially different from that already described.

The rate at which a road can be graded up with a grading machine varies to a great extent, and depends largely on the character of the soil. Where the original cross section of the ground is approximately level, such as that shown in the model (Pl. II), the cross section of the finished road similar to that shown in figure 12, and the soil conditions not unfavorable, a grading machine drawn by six well-trained horses should cut out the side ditches and shape the road in from 20 to 35 round trips. Allowing for a reasonable amount of lost time, the rate at which the team travels should average from 1½ to 2 miles per hour, and under the circumstances assumed above, the length of road graded per day should average not less than one-fourth mile. Such favorable conditions seldom are found for any considerable stretch of road, except in the prairie sections of the



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EARTH ROAD MODEL, SHOWING RESULTS OF SUCCESSIVE OPERATIONS WITH GRADING MACHINE.

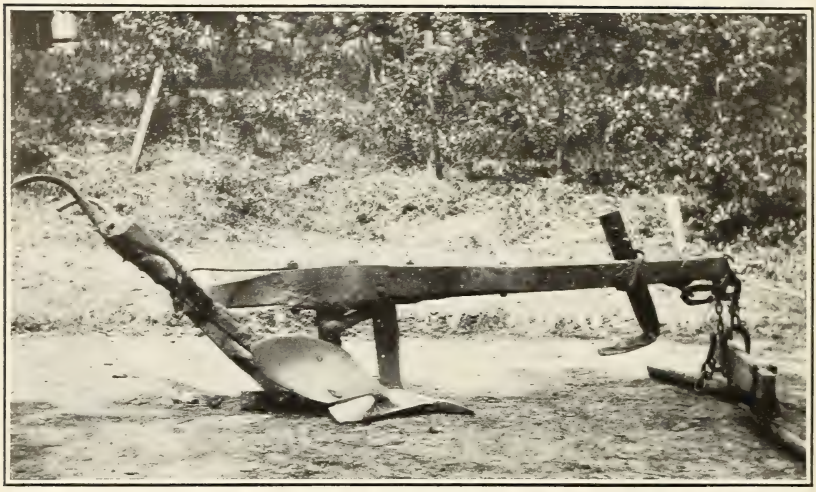

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FIG. 1.—TURN PLOW.

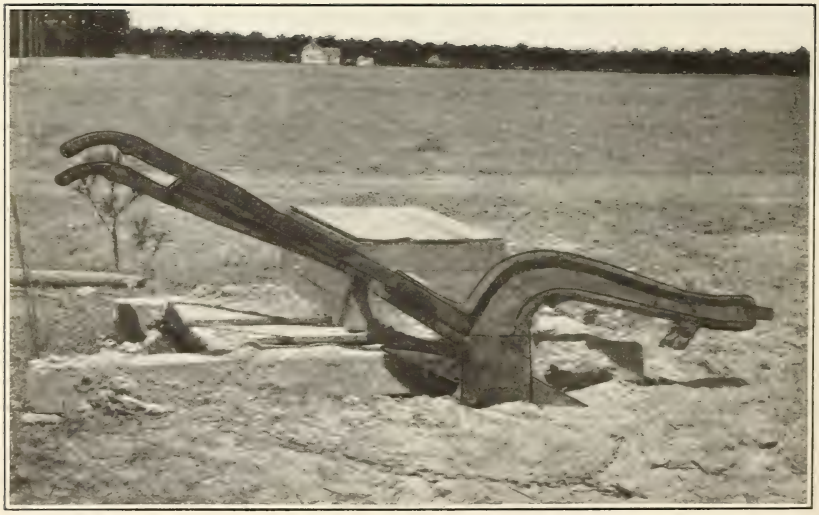


FIG. 2.—ROOTER PLOW.

Middle West, and the average rate of grading with a grading machine is, therefore, much less than one-fourth mile of road per day.

USE OF ELEVATING GRADER.

Figure 14 shows an elevating grader at work. The essential features of this machine are a plow with a heavy moldboard, an elevating belt, a suitable frame for supporting the plow and belt, and driving and adjusting mechanisms for operating the belt and controlling the work. The plow loosens the material and throws it onto the belt, which conveys and deposits it either in the roadbed or wagons.

Elevating graders are adapted especially to building up embankments with material excavated from shallow borrow ditches along

OPRRE8572

FIG. 14.—Elevating grader at work.

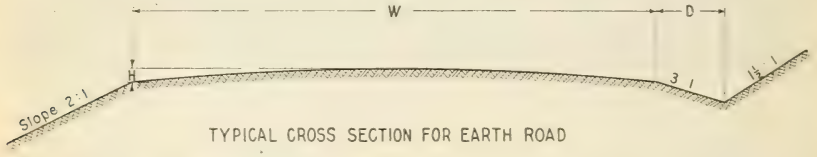
each side of the road. They also may be used to advantage in excavating long, shallow, through cuts and loading the material thus excavated into wagons for use in building up embankments at other points. The latter use, however, is restricted to situations where there is sufficient space to operate the grader and at the same time afford passageway for the teams and wagons to follow under the end of the belt to receive the successive loads as the grader is drawn forward.

It is customary to employ a traction engine for operating the elevating grader, though teams are used sometimes. Ordinarily, the machine may be operated successfully either with a 25-horsepower tractor or with 12 well-trained horses. A well-constructed elevating grader, adapted to either horse or tractor power, may be purchased at an average price of about $900.

The rate at which earth can be excavated with an elevating grader is relatively very high when conditions are favorable and the grader can be kept moving. But there are a number of rather complicated parts about such a machine which sometimes get out of order, and the work also is hampered frequently by many unforeseen contingencies, such as "bogging" of the wheels, choking of the plow or the elevator belt, occurrence of buried stumps or stones in the excavation, etc. For these reasons the actual capacity of elevating graders, considered over a long period, seldom is more than about one-third or one-half the rated capacity, and where the material is loaded into wagons as it is excavated the actual capacity of the machine may be reduced still further. Elevating graders of the size used ordinarily in road work have a rated capacity of about 100 cubic yards per hour.

USE OF SCRAPERS, WAGONS, ETC.

To grade a road of any considerable length, no matter where it is located, usually will require a considerable amount of work with devices other than the grading machine and elevating grader. The latter machines, as previously explained, may be very economical for special conditions to which they are adapted. But these special conditions seldom prevail for more than comparatively short stretches of road without sections intervening which require that a relatively large volume of material be moved from excavation to embankment within a distance of only a few hundred feet. Figure 15 shows a typical cross section for an earth road, where the grading



TYPICAL CROSS SECTION FOR EARTH ROAD

"W" width of road between ditches, not less than 20 feet
"D" varies from 2 feet to 6 feet depending on the rainfall and grade.
"H" crown, varies from ½ inch to the foot for level grade to 1 inch to the foot for a grade of 5%

FIG. 15.

machine hardly could be used advantageously except for finishing the road surface. To accomplish work of this kind economically, the devices for loosening, loading, and hauling the material must all be adapted to turning around quickly in a small space and, not infrequently, must be such as to be handled readily over very rough ground. Such implements as wagons, wheeled scrapers, drag scrapers, and plows therefore should form a part of the equipment on practically all road-grading projects.

The choice of proper implements to employ in moving material from excavation to embankment depends, first, on the nature and quantity of the material to be moved, and, second, on the length of

haul. In general, where the material consists of earth it is loosened with plows and the economical method of hauling is fixed by the haul length about as follows:

For lengths of haul not exceeding 150 feet, drag scrapers; for lengths of haul between 150 feet and 600 feet, wheeled scrapers; for lengths of haul above 600 feet, wagons. Where the material consists of solid rock it must be loosened by drilling and blasting and practically always is hauled in wagons or carts, regardless of the haul length.

The two types of plows commonly used in road grading are shown in Plate III, figures 1 and 2. The former is the type generally used for loosening ordinary soils, while the latter is used for breaking up hardpan, old road surfaces and other earth unusually difficult to loosen. Either type is drawn by four horses, or in some cases by a traction engine, and is operated by three men, including the driver. Plows of the type shown in figure 1 of Plate III average about 150 pounds in weight and sell at an average price of from $12 to $18, but heavier plows of this type range in cost up to about $30. With average soil conditions they may be made to turn a furrow about 7 or 8 inches deep and from 8 to 10 inches wide. The hardpan plows of the type illustrated in figure 2 of Plate III vary considerably in weight and selling price but cost more than the turn plows. One reason for the higher cost is that the points must be made of a very high grade of steel in order to be durable.

OPRRE5866

FIG. 16.—Drag scrapers at work.

A drag scraper of the common type is illustrated in figure 16. Such scrapers are made in 1-horse, 1½-horse, and 2-horse sizes, which have respective rated capacities of 3, 5, and 7 cubic feet. Drag scrapers have an average weight, when empty, of from 75 to 100 pounds, and an actual capacity of about three-fourths the rated capacity. The price, f. o. b. factory, averages about from $4 to $6 per scraper.

In operating drag scrapers the drivers also may load and empty the scraper, but frequently it is economical to provide additional

laborers for this purpose. With a haul length of 100 feet and the teams moving steadily, one laborer should be able to load or empty and spread the material for about three scrapers. For scraper work to be effective the material to be excavated must be thoroughly loosened by the plows and should be free from large roots or stones. Where such obstructions occur time is saved by having them removed by hand during the progress of the plowing.

The average small organization for carrying on road-grading work with drag scrapers is made up about as follows:

Force:	Tools:
1 foreman.	6 drag scrapers (capacity 5 cubic feet).
4 to 6 scraper drivers.	1 road plow.
2 laborers for loading scrapers.	2 picks.
2 laborers for dumping and spreading.	2 axes.
1 driver for plow.	2 mattocks.
1 laborer to hold plow.	3 shovels.
1 laborer for trimming shoulders, etc.	
4[1] to 6 two-horse teams for scrapers.	
1 or 2 two-horse teams for plow.	
Total, 1 foreman, 14 laborers, and 7 teams.	

The force employed should vary somewhat with the haul length, which is usually between 25 feet and 150 feet. Under average conditions an organization such as that described above should move from 300 to 350 cubic yards of earth per 10-hour day.

An objectionable feature of drag-scraper work is that the embankments tend to settle very irregularly. The reason is that the successive loads are not spread out uniformly as they are dumped, but are deposited as a succession of rather compact cores with the intervening spaces consisting of comparatively loose material. The loose material settles more than the compacted spots, and this unequal settlement produces pockets in the surface which hold water and gradually become deepened under the action of traffic. Where the material to be moved is loose and light, such as the prairie soils of the Middle West, this objection can be overcome largely by substituting Fresno or Buck scrapers for the common type of drag scrapers.

Fresno scrapers are made in several different sizes and range in capacity from about 8 to 12 cubic feet. They are drawn usually by three or four horses, and can be operated in almost as small a space as drag scrapers. Their average cost is from $15 to $20 each. One principal advantage of Fresno scrapers is that the runners may be adjusted to spread out the load to any desired depth from 2 or 3

[1] Where necessary, one of the scraper teams may be used to help the plow team.

inches up to 12 inches and this better distribution of the material in the embankment tends to prevent inequalities from developing in the finished road surface.

Wheeled scrapers (fig. 17) are used to a greater extent in road grading than either drag scrapers or wagons. The reason for this is that in road work the haul length falls, more frequently than otherwise, within the limits for which wheeled scrapers are economical. Several different sizes of such scrapers are in ordinary use, but the size employed most commonly has an actual load capacity of from 11 to 15 cubic feet, according to how heavily the load is heaped. Scrapers of this size ordinarily sell for from $35 to $50 f. o. b. factory.

In operating wheeled scrapers the material is loosened by plowing, in the manner already described, and is loaded by the scooping action of the scraper. Two horses usually are sufficient to draw the scraper after it is loaded, but a second team, called a snatch team, is hitched in at the front of the tongue to assist in loading. The snatch team should consist of either two or three horses, according to the character of the material, and one snatch team should serve several scrapers. The loading and dumping of the scrapers are done by laborers provided for that purpose and not by the drivers.

OPRRE14571

FIG. 17.—Wheeled scraper.

A small organization for carrying on grading work with wheeled scrapers may be made up about as given below:

Force:
- 1 foreman.
- 6 to 11 drivers.
- 1 laborer for plowing.
- 2 laborers for loading scrapers.
- 2 laborers for dumping and spreading.
- 1 laborer to trim slopes, etc.
- 1 two-horse team for plow.
- 4 to 8 two-horse teams for scrapers.
- 1 or 2 two-horse snatch teams.

Total: 1 foreman, 17 laborers, 11 teams.

Tools:
- 8 wheeled scrapers (capacity 11 to 15 cu. ft.).
- 1 road plow.
- 2 picks.
- 2 mattocks.
- 2 axes.
- 3 shovels.

The force employed should vary with the haul length, usually from 150 feet to 600 feet. Six to eight scrapers should be employed where the haul exceeds 250 feet. Where necessary one of the snatch teams may be used to assist the plow team.

Such an outfit should move from 200 to 250 cubic yards of earth per 10-hour day.

Several types of dump wagons are used in road-grading work. Probably the most common is the ordinary farm wagon fitted with a slat-bottomed bed as illustrated in figure 14. The most usual capacity for wagons of this kind is about $1\frac{1}{4}$ cubic yards. Patent dump wagons (fig. 18) are made in sizes ranging from 1 to 3 cubic yards capacity, and, in general, are preferable to the slat-bottomed wagons, because they are turned around more easily in a short space and are much more easily dumped. Patent dump wagons of the size employed ordinarily in road work ($1\frac{1}{2}$ cubic yards capacity) sell at an average price of about $150, f. o. b. factory, which is a relatively high cost as compared to farm wagons, the price of which seldom exceeds about $50 or $75. One-horse carts are used sometimes instead of wagons, but two-wheeled vehicles are very severe on horses, especially when hauling over rough ground, and therefore the use of carts is not recommended.

FIG. 18.—Dump wagon.

Where wagons are used for hauling and the excavation is fairly light, it is customary and economical to loosen the material with plows and to load it into the wagons with hand shovels. If the excavation is fairly heavy and sufficient in amount to warrant the additional outlay, it is economical sometimes to employ a small steam shovel (fig. 19) for loosening and loading the material. The steam shovels used ordinarily in road work have a dipper capacity of from one-half to three-fourths of a cubic yard. Under fairly favorable conditions steam shovels of these sizes can be made to load from 400 to 500 cubic yards of stiff earth per 10-hour day.

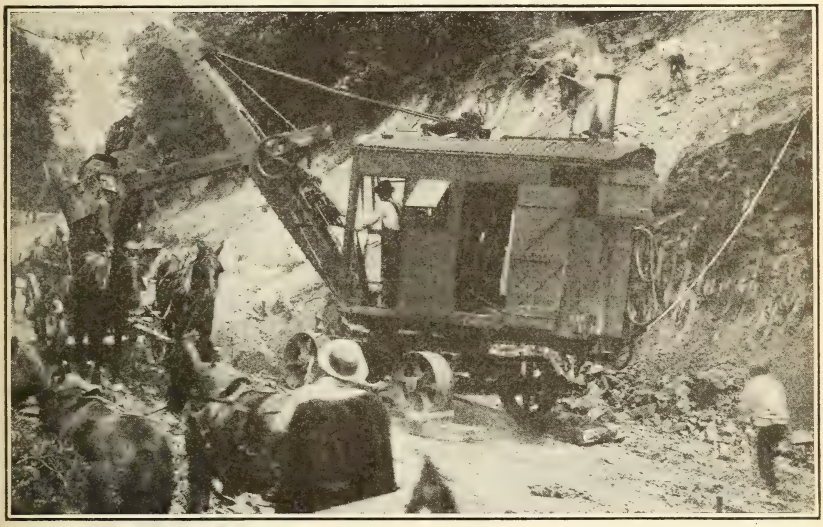
Where the material is loosened by means of plows and hauled in wagons the average small grading gang may consist of 1 foreman, 3 laborers, and 2 teams for plowing, 9 laborers for loading, 2 laborers for spreading, and a sufficient number of teams for hauling to

keep the above force busy. With such a force the number of wagons for maximum efficiency varies from about 3 for a 500-foot haul up to about 12 for a haul of 1 mile. Ordinarily, one of the plow teams may be employed in hauling for at least a part of the time.

Under average conditions such a force as that described above should move about 150 cubic yards of earth per 10-hour day.

BUILDING EMBANKMENTS.

One of the most important considerations connected with the grading of an earth road is the stability of the embankments. Where a road is situated in a cut and is well drained, it is not likely



OPRRE13175

FIG. 19.—Steam shovel at work.

to be affected seriously by such agencies as shrinkage, settlement, and slipping, any one of which may injure or destroy a road situated on a poorly constructed embankment. In grading a road, therefore, the methods employed in building the embankments are deserving of much more careful scrutiny than those employed in making excavations.

To prevent a road over an embankment from being damaged by shrinkage of the material forming the embankment, the material must be free from vegetable matter and uniformly compacted as it is deposited. Where the road surface is to be of earth, the embankment usually may be compacted sufficiently to prevent injury from shrinkage by spreading the material in relatively thin horizontal layers and letting each layer be compacted by the grading teams as the succeeding layer is being spread. Layers of ordinary earth, not

more than about 12 inches thick, can be compacted fairly well in this way, provided that the grading teams are made to travel over the entire surface of each layer, and that the material is spread uniformly. Where the road surface is to be of some highly improved type, each layer of the embankment should be rolled thoroughly with a power roller weighing not less than about 10 tons.

Settlement of embankments, aside from that due to shrinkage, may be caused by the gradual flattening of the slopes or by lack of stability of the ground surface over which the embankment is constructed. The question of proper slopes for various materials has been discussed. The question of ground surface stability usually does not arise as a grading problem except where an embankment is being constructed over very marshy land. If proper precautions are not observed, the embankment material may be absorbed gradually by the marsh until the entire roadbed has disappeared, an occurrence which is not infrequent.

Where drainage of the marsh is impracticable, the lower portion of the embankment, which would come in contact with the marsh water, should be formed of some nonslaking material that will cement together and distribute the weight of the embankment over the entire bottom area. Some varieties of gravelly clay are excellent for this purpose. Where the marshy matter is very soft and deep, it may be necessary to lay a wide foundation bed of logs, or fascines, upon which to construct the embankment, but such a foundation bed would not obviate the necessity for using a nonslaking material in the lower portion of the embankment.

Where embankments are constructed on very sloping ground, or where old embankments are to be widened, there always is a tendency for the new material to slip along the plane of separation. In such cases the old surface should be roughened before the new material is deposited. Where the old surface is earth, it usually can be roughened sufficiently by plowing a series of rather deep furrows about 2 feet apart. Old rock surfaces ordinarily are fairly rough to begin with, but to prevent slipping it may be necessary in some cases to blast steps into such surfaces before depositing embankment material.

Retaining walls, slope walls, and cribbing also are frequently used to prevent embankments from slipping.

FINISHING THE SURFACE.

No matter how the grading of an earth road may be accomplished it usually is economical to bring the road surface to its final shape by means of a grading machine. In making excavations it is not generally considered practicable to form the crown and side ditches

with scrapers or hand tools alone, and the cross section is, therefore, frequently left approximately flat. The grading machine is then used, in the manner already described, to produce the required cross section.

After the road has been finished with the grading machine, it should be given frequent attention until the embankments have finished settling and the surface has become thoroughly compacted by the action of traffic. Generally a period of several months should elapse after a road is graded before it is considered complete, and such settlements and irregularities as develop during this period should be corrected by the use of either a grading machine or a road drag. A description of the road drag and a discussion of its uses are given on page 58.

CONSTRUCTION COSTS.

Aside from drainage structures, the principal item of cost attached to the construction of an earth road is for the grading. The cost of grading varies greatly, according to the condition of the weather, the nature of the material to be excavated, the efficiency of labor, teams, and machinery, etc., and seldom can be estimated in advance with any great degree of accuracy. On this account average costs based on past experience may be very misleading when applied to a particular project. In the following statements and data an effort is made to show the approximate range of cost rather than the average.

The first step in estimating the cost of grading a given road is to ascertain the quantities of work to be done. After the quantities have been determined the cost may be estimated in either of two ways. First, the organization for carrying on the work may be planned in detail and the estimate arrived at by considering the cost of maintaining such an organization, together with the rate at which it may reasonably be expected to accomplish the work. Second, the cost per cubic yard for excavation and the cost per mile for shaping the roadway may be estimated at flat rates. The first method is the most accurate, though the latter is the one employed most frequently.

If the prices for labor and teams are known, the cost of grading under a given set of conditions may be estimated from the data already given. A frequent source of error in estimating costs in this way is that such items as supervision, lost time for which payment must be made, repairs to tools and machinery, and depreciation of the plant are overlooked.

The following data (Tables 5 and 6) are intended to furnish a rough guide in making estimates of grading cost at a flat rate per cubic yard. They are based on labor at 15 cents per hour; horses

at 12½ cents per hour. The depreciation of grading equipment and repairs are figured at 5 per cent per month while in use, and it is expected that the force will be organized economically and managed efficiently.

TABLE 5.—*Grading machine work.*

Assumed conditions: Original cross section flat; finished cross section similar to figure 12; team to consist of six to eight well-trained horses; no material moved longitudinally.

Character of soil.	Cost per mile.
Light prairie free from stumps, roots, etc.	$60 to $80
Average clay loam	100 to 150
Heavy clay, moderate amount of sod and roots, plowing necessary throughout	200 to 250
Heavy clay, exceptionally difficult conditions	From $250 up.
Crowning and shaping road which has been graded with scrapers, etc.	$50 to $75

TABLE 6.—*Excavation and embankment.*

Assumed conditions: All material to be loosened with plows or by blasting, and to be moderately dry when handled; hauling to be done by means of drag scrapers, wheeled scrapers, or wagons.

Kind of material.	Average haul length.	Method of hauling.	Average cost per cubic yard.	Remarks.
	Feet.		*Cents.*	
Light sandy loam, free from roots, etc.	50	Drag scrapers	10 to 15	Material assumed to be such that little or no plowing is necessary.
	100	do	12 to 20	
	300	Wheeled scrapers.	16 to 25	
	1,000	Wagons	25 to 40	
Average clay loam, free from roots, etc.	50	Drag scrapers	15 to 20	Material such as to be loosened with plow drawn by two horses.
	100	do	17 to 25	
	200	Wheeled scrapers.	23 to 35	
	1,000	Wagons	32 to 50	
Heavy clay	50	Drag scrapers	18 to 25	4 horses required for plowing.
	100	do	21 to 30	
	300	Wheeled scrapers.	28 to 38	
	1,000	Wagons	40 to 55	
Hard pan or loose rock.	300	Wagons	40 to 65	Low prices apply where material may be loosened with 4 horses and hard-pan plow. High prices where blasting is necessary.
	1,000	do	45 to 75	
Solid rock	300	Wagons	$0.65 to $1.50	High prices apply where stone is hard and excavation shallow.
	1,000	do	.75 to 1.75	

SAND-CLAY ROADS.[1]

A road surface constructed of sand and clay mixed in proper proportions possesses the resisting powers of the sand in wet seasons and of the clay in dry seasons, and frequently is superior to either in all seasons.

Natural sand-clay soils occur to some extent in nearly all sections of the United States, and in many localities are rather widely distributed. Ordinary earth roads frequently contain short sections

[1] This discussion is based largely on information contained in Farmers' Bulletin 311, "Sand-Clay and Burnt-Clay Roads," which was prepared by William L. Spoon, senior highway engineer, and has been read and revised by E. W. James, general inspector, U. S. Office of Public Roads and Rural Engineering.

which are constructed of such soil, and it happens occasionally that for a considerable distance along a road the soil contains just the proper proportions of sand and clay to produce an excellent road surface for moderate traffic under all weather conditions to which the road is subjected. But, in general, such soils occur only for limited distances, and to secure a continuous surface of this kind, the necessary material must be hauled to the road, spread, and compacted after the grading is completed otherwise. More generally, perhaps, the soil composing the roadbed is deficient in only one of the necessary constituents, sand or clay, and it frequently may be economical to construct the surface by supplying the necessary sand or clay and mixing it with the natural soil of the roadbed, rather than to provide a surface of natural sand-clay material. It may happen, also, that the roadbed contains no material suitable for use in constructing the surface, and that sand and clay are more readily available separately than ready mixed. In such case both materials may be hauled to the road and mixed in place to form the surface.

In order to distinguish between common earth roads, which are constructed wholly of the natural soil as it occurs along the road, and those which have been surfaced with especially selected or especially prepared earth which contains sand and clay mixed in such proportions as to increase the resistance to wear of the surface as described above, the latter are designated sand-clay roads. This designation evidently includes most of the so-called "topsoil" roads, because topsoil which is especially suited for use in road surfaces generally possesses that quality by virtue of the sand and clay which it contains.

The sand-clay method of construction has produced its best results in the Southern States, where deep freezing is not a serious factor and where materials suitable for such construction probably are more widely distributed than in any other section of the country. There are many sand-clay roads in the South Atlantic and Gulf States over which heavy loads of cotton and other farm products are hauled throughout the year and which remain continuously in good condition with a comparatively very small outlay for maintenance. And there are innumerable cases where sand-clay surfaces, constructed of even rather inferior materials, have so improved intolerable stretches of sandy or muddy road as to provide for at least fairly comfortable travel throughout the year. Examples of the latter kind are by no means peculiar to the Southern States, but are to be found in nearly every section of the country. Table 7 shows the mileage of sand-clay roads in several representative States for 1909 and 1914, respectively, and illustrates how the popularity of this type of construction is increasing.

TABLE 7.—*Mileage of sand-clay roads in several representative States for 1909 and 1914.*

States.	Sand-clay mileage.		States.	Sand-clay mileage.	
	1909	1914		1909	1914
New Jersey	None.	561	Kansas	202	758
Virginia	186	1,151	North Carolina	730	4,313
Alabama	1,107	1,916	Texas	2,254	3,684

The construction of sand-clay roads is essentially a matter of employing locally available materials to the best practicable advantage in producing an improved earth road surface. To do this involves an intelligent selection from the local materials and an adaptation of the construction method employed to the material selected. These two features of the work will be taken up separately in the order mentioned.

SELECTION OF MATERIALS.

The questions that ordinarily must be given principal consideration in the selection of materials for a sand-clay road surface are: (1) Is the soil composing the roadbed such that, if local sand or clay were admixed with it in proper proportion, a durable road surface can be produced? (2) Is topsoil of a suitable character available for use as a surfacing material? (3) Can a sufficient quantity of natural sand-clay subsoil for surfacing the road be obtained conveniently? (4) Can the two constituent materials be obtained separately and mixed in place on the road? (5) If a variety of materials are available, what selection or combination would give the best results and prove most economical in the long run? In deciding these questions, there are three ways in which the judgment may be assisted materially. These are, in the order of their importance, by means of service comparisons, field examinations, and laboratory tests. The questions and the customary manner of deciding them will be discussed briefly in the following paragraphs.

THE SOIL OF THE ROADBED.

In order to determine whether the soil of a given roadbed may be incorporated advantageously in a sand-clay road surface, it is necessary, of course, to consider the quality of the other local materials available for mixing with it, since the fitness of the roadbed soil for use in the surface necessarily must be limited by the quality of the other constituent material. In general, there are two conditions where the soil of the roadbed may be used advantageously in constructing the surface. One is where the roadbed is very sandy and plastic clay is more readily available for use in the surface than

a natural mixed sand-clay. The other is where the roadbed consists of a good quality of plastic clay and sand is available for the surface. In either case the appearance of the roadbed material may sometimes be very misleading under certain weather conditions, and before deciding whether it is suitable for use in the surface its behavior should be observed for all weather conditions to which the surface will be subjected.

For example, an earth road which appears very sandy in dry weather in reality may be composed of soil that will be converted into mud by even a very moderate rain. This is particularly true of soils that contain a high percentage of either very fine sand or silt. Where the roadbed is composed of such soil, no part of it should be incorporated in a sand-clay surface. The sand contained in a sand-clay surface is supposed to supply stability to the surface in wet seasons, and the roadbed material, to be adapted for this purpose, must be composed of sandy soil that will increase in stability with an increase in moisture content, and will not become muddy under any circumstances.

On the other hand, a roadbed that in wet seasons appears to be composed of clay suitable for use in a sand-clay surface may crumble into fine dust on drying out under even very light traffic. While a road surface constructed by mixing sand with soil of this kind might be a considerable improvement over the old earth road in both wet and dry weather, it would be very much inferior to a surface constructed by mixing together a good quality of nonslaking clay and sand.

TOPSOIL.

In the Piedmont and upper Coastal Plain regions of the South Atlantic States it happens often that the soil over limited areas of land is of such quality that a road surface made of it will possess all the desirable characteristics of a well-constructed sand-clay surface. A rather large mileage of roads has already been surfaced with soil of this kind and much of it is giving excellent satisfaction. Such roads are known locally as "topsoil roads."

The best topsoil for road surfacing usually is found in fields which have been under cultivation for a number of years. The probable reason for this is not only that cultivation produces a more intimate mixture of the soil constituents, but that the repeated aeration tends to improve the stability of the soil by causing the oxidation of certain component minerals. Also, where the original soil contains a too high percentage of clay, cultivation may have improved its quality by increasing the rate at which clay is leached out. Since cultivation ordinarily extends to a depth of only a few inches below the ground surface, the layer of soil suited for use in road surfacing is, in most

cases, very thin. The usual variation in the depth of this layer is from 4 to 12 inches. A suitable quality of topsoil is produced sometimes by agencies other than cultivation, when the depth may be considerably greater than 12 inches.

The safest guide in identifying topsoil that will make a satisfactory road surface is the service test, and, fortunately, it is nearly always possible to make this test by simply observing the condition of a section of road already constructed of the soil in question. The best method to follow in making a selection is to pick out such sections of earth road in the vicinity of the one to be surfaced as remain continuously in good condition. Then, if practicable, obtain the soil intended for the new road from the fields adjacent to the best sections of this good earth road. Otherwise employ specimens of the soil from these fields to compare with other available soils and base the selection on such comparisons. When comparisons are not conclusive the various kinds of available soil should be tried out on a small scale before any considerable area of topsoil surface is constructed, because there is at present no other reliable method for comparing the relative excellence of different topsoils and it is very easy to be misled into a wrong selection by incomplete laboratory tests.

The following list of characteristics usually belonging to topsoil of a satisfactory quality at least may prove helpful in selecting soils upon which to make the service test referred to above:

1. Some of the best topsoils so far discovered are of granitic origin; that is, the soil has been formed by the decomposition of granite.

2. Good topsoil usually has a very "gritty" texture, and when rubbed between the fingers this characteristic should seem more pronounced than any other.

3. Samples of soil taken from a number of first-class topsoil roads and subjected to mechanical analysis have shown an average sand content of from 50 to 75 per cent and an average clay content of from 25 to 50 per cent. But it appears that satisfactory results have been obtained most frequently where the sand content ranged between 65 and 70 per cent and the clay content between 30 and 35 per cent.

4. The color of good topsoil is more frequently gray than otherwise, but color is by no means an index to quality. Several cases have been reported where excellent results were obtained with a soil of dull-red color, while, again, a dark-brown soil has proved entirely satisfactory. Usually the color of the soil gradually becomes lighter after it is placed on the road, and some of the best gray soils have become almost white after a few years' service.

5. The soils designated ordinarily by farmers as "gray grit," "bright tobacco soil," "upland soil," and "rotten granite" have been found very frequently to possess the proper characteristics for

a good quality of topsoil. These names have considerable significance in some localities, but may mean practically nothing in others.

CLAY AND SAND.

Nearly all clays, as they occur in nature, contain more or less sand. Those in which the percentage of sand is sufficiently high to give the material a character decidedly intermediate between sand and clay are called natural sand-clay. Ordinarily, at least 40 per cent of sand is required to produce this intermediate character in a pronounced degree, and from 60 to 70 per cent usually is required to produce a first-class sand-clay surfacing material, though these percentages depend to a considerable extent on the respective qualities of the two constituent materials.

In general, the quality of clay is much more uncertain than that of sand and usually it is very difficult to determine in advance just what results may be expected from the use of a given clay in a sand-clay surface, except by means of a service test. But some time is required to make the service test, and, where none of the clay proposed for use occurs in an existing road surface, it may be very desirable to test the available material according to some quick method, so as to exclude from the service tests all clays which would not be likely to prove satisfactory. Some of the simplest methods for determining the probable wearing qualities of clay, or of a natural sand-clay mixture, by means of field inspection and laboratory tests are described below.

(1) To determine the proportion of sand present in clay, collect a representative sample of the clay and dry it thoroughly. After weighing the dry sample, place it in a vessel several times larger than the sample and wash out the clay content by filling the vessel repeatedly with water, agitating the clay and pouring off the muddy water. When all the clay has been washed out, dry the sand and weigh it. Then the proportion may be computed from the original weight and the weight of the sand. If the material tested happens to be of good quality of sand-clay, the weight of the sand will be about two-thirds that of the original sample.

(2) To compare the slaking qualities of two or more samples of clays, make up each sample into several balls of the same weight, dry out the balls thoroughly, and place them in water so that they will be covered entirely. The balls which hold their shape longest after being placed in the water have the highest resistance to slaking, and the clay which they represent usually is to be preferred for use in the road surface. If this test is to be at all conclusive, however, the different samples should contain about the same percentage of sand, and if there is much doubt about the sand content, it should be

determined for each sample prior to the time of making the slaking test, so that the percentage may be corrected by adding sand or clay. This test may be employed also to compare the slaking qualities of the same clay when mixed with different percentages of sand, and when so employed may afford a valuable guide in fixing the proper proportions for an artificial sand-clay mixture. In making the test several balls should be made and tested from each kind of clay, so as to afford check results. Also, in all the tests care must be exercised to keep the different samples from becoming confused after the balls are placed in the water. To do this, identifying marks may be placed upon the balls, or the balls from each sample may be placed in a different part of the containing vessel.

(3) The amount which clay shrinks on drying out also may be a measure of its fitness for use in a sand-clay surface. The shrinkage may be tested by observing the behavior of the clay balls while they are being dried out, when those which shrink most will develop most cracks. Other things being equal, the sand-clay mixture showing the smallest shrinkage is best suited for use in a road surface.

(4) Valuable comparative information regarding different available clays or sand-clay mixtures may be gained sometimes by simply observing exposed surfaces, where the materials outcrop, under different weather conditions. The best clays will be capable of standing on relatively steep slopes and will develop fewer surface cracks upon drying out after a wet season. They also will be little affected by frost and will appear dense and firm in dry weather.

(5) To test the suitability of sand for use in a sand-clay surface, place a sample of the sand in a vessel containing water and agitate the water until the sand is thoroughly in suspension. Then, after the sand has been allowed a few moments to settle, pour off the water slowly. If of good quality, the sand will not be carried out with the water but will remain in the vessel until practically all of the water has been drained off. Sand containing a large percentage of mica or other light mineral matter will not meet this test and is not generally suitable for use.

(6) The methods described above for testing sand-clay materials are based on the assumption that the selection must be restricted to materials locally available and are intended simply to aid in comparing the relative merits of such materials. But these methods can, of course, be adapted to more exact laboratory practice if so desired.[1]

[1] A rather detailed plan for laboratory procedure, which has been followed to some extent in connection with the sand-clay roads of Georgia, is described by John C. Koch in the "Transactions of the American Society of Civil Engineers," Vol. LXXVII, December, 1914, p. 1454.

CONSTRUCTION METHODS.

The proper method to employ in constructing a sand-clay road surface depends on the conditions to be met. In general, there are four distinct sets of conditions, all of which may occur in the same locality, or even on different sections of the same road. These are:

Case 1, where the original roadbed is sandy and it is desired to construct the surface by admixing clay;

Case 2, where the original roadbed is composed of clay and it is desired to construct the surface by admixing sand;

Case 3, where it is desired to construct the surface of topsoil or other natural sand-clay mixture without admixing any of the roadbed material;

Case 4, where it is desired to supply the clay and sand separately and mix the two materials together in place to form the surface.

Before discussing the different cases separately, the general ends which all of the construction methods should aim to attain will be summarized briefly.

(1) The questions of location, design, drainage, grading, etc., are, if anything, more important in the case of sand-clay roads than in the case of earth roads. These questions have all been discussed in another part of this bulletin.

(2) The amount of clay contained in a finished sand-clay road surface should be only slightly more than sufficient to fill the voids in the sand. Ordinarily about one part of clay to two parts of sand gives satisfactory results, though the proper proportion for any particular case can be determined best by experiment.

(3) For average country-road traffic and a stable roadbed, the depth of a sand-clay surface should be about 8 inches after it is compacted. If clean sand and pure clay were used to make the mixture, the respective depths of the sand layer and the clay layer required would be approximately 8 inches and 4 inches, measured loose. It is customary to decrease the surface thickness from center to sides, with a feather edge extending out over the shoulders, but this practice makes it necessary for most of the traffic to use the center of the road, and heavy vehicles using the edge of the surface are liable to break through the surfacing material.

(4) In constructing a sand-clay surface, the two constituent materials should be thoroughly and intimately mixed together in all cases. In making artificial mixtures, therefore, much plowing and harrowing are required.

(5) No matter what method is followed in constructing a sand-clay surface, traffic usually must be depended upon to puddle and compact the surfacing material, and the road never should be con-

sidered complete until after it has been subjected to traffic for a considerable period. During this period the surface should be kept in shape by repeated dragging, and if necessary additional sand or clay should be supplied at points which show weakness owing to these materials not having been mixed in proper proportions.

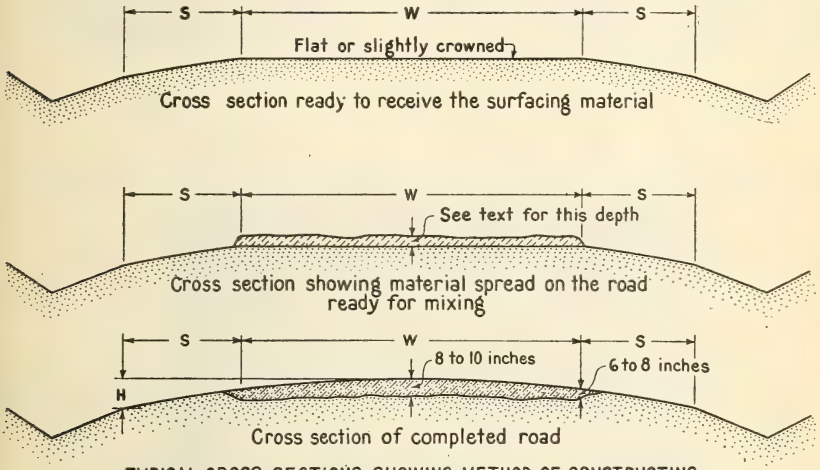
Other features of the construction can best be described separately for each of the four sets of conditions mentioned above.

Case 1.—To construct a sand-clay surface by admixing clay with sand from the roadbed, first grade the roadbed in the manner already described for earth-road construction, but keep the crown flat on the portion to be surfaced. Then spread clay over that part of the roadway which the surface is to cover, to such depth that, when it is mixed with the sand of the roadbed, a surface about 8 inches thick, after compacting, will be obtained. The loose depth of clay necessary to secure a finished surface 8 inches thick usually will vary from 4 inches to 6 inches, according to the amount of sand the clay contains. After the clay has been spread, plow up sand from beneath in sufficient quantity to make the net proportion of sand to clay about 2 to 1. Ordinarily the plow furrows should extend down into the sand from 4 to 6 inches, depending on the compactness of the roadbed and the amount of sand originally present in the clay. But it is better to have too little than too much sand, because it is easier to add sand from the roadbed than to haul additional clay. Next harrow the surface with a disk harrow. Repeat the operations of plowing and harrowing until the sand and clay are mixed thoroughly and uniformly. Then shape up the surface with a grading machine or road drag and permit traffic upon it. After the first soaking rain, plow and harrow the surface again until the surfacing material practically becomes mud, after which shape up the surface and keep it in shape by repeated dragging until it has dried out and is thoroughly compacted. Watch the road carefully for several months after it is first constructed, to correct deficiencies of sand or clay and to keep the surface in shape. The cross sections shown in figure 20 illustrate the principal steps involved in contructing a sand-clay road surface according to the method just described, as well as the one described in the following paragraph.

Case 2.—To construct a sand-clay road surface by admixing sand with clay from the roadbed, the process is exactly similar to that described for Case 1, except that sand is spread over the graded roadbed and clay is plowed up from beneath to mix with it. The depth to which the sand should be spread for an 8-inch finished surface usually varies from 4 inches to 8 inches according to the amount of sand contained originally in the clay of the roadbed. The depth to which the plow furrows should extend down into the clay usually varies from about 3 inches to about 5 inches, and depends on the sand

content of the clay and the compactness of the roadbed. It should be borne in mind that, in this case, it is better to have a surplus of sand than a surplus of clay in the surface, because the former is more easily corrected.

Case 3.—Figure 21 illustrates the two principal steps involved in constructing a sand-clay surface with topsoil or other natural sand-clay mixture. The roadbed should be graded in the usual way, except that the portion to be surfaced should be trenched out with the grading machine to receive the surfacing material. The surfacing material should be spread to such a depth that it will be at least 8



TYPICAL CROSS SECTIONS SHOWING METHOD OF CONSTRUCTING SAND-CLAY ROAD BY MIXING SAND OR CLAY WITH THE ROAD BED MATERIAL.

"W" should be at least 12 feet for single track road, and "S" generally not less than 5 feet, for double track "W" should be not less than 14 feet, and "S" not less than 3 feet. "H," crown, varies from ½" to the foot for level grade, to 1" to the foot for a grade of 5%.

FIG. 20.

inches thick at the center when compacted. After this is done permit traffic upon the road and keep the surface in shape with a road drag while it is being compacted. Where surfacing material may be obtained cheaply trenching is frequently omitted altogether, and the artificial surface is extended out over the shoulders.

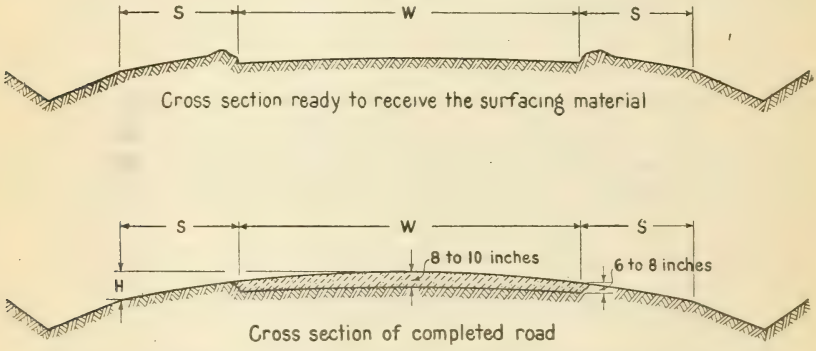
Case 4.—Where it is necessary to bring the sand and clay on the road separately and mix them in place, the method employed should be a combination of the methods already described. That is, a trench should be formed with the grading machine to receive the bottom layer of material, which may be either the sand or the clay, and the top layer should then be spread and the mixing done as described in Case 1 or Case 2. The depths of the respective layers should be such as to secure a completed surface at least 8 inches thick, and the proportions should be fixed in the manner already described in discussing the other cases. Where the roadbed material

consists of clay which is not considered suitable for use in the surface, it is well to spread the sand layer first and to make its depth more than is sufficient for use in the surface. The surplus sand which remains under the completed surface then will serve to improve the drainage of the road.

Plate IV, figures 1, 2, and 3, illustrates the several principal features involved in the construction of a sand-clay road and supplements the information given in the text.

COST OF SAND-CLAY ROADS.

From the foregoing discussion of construction methods, it is apparent that the conditions under which sand-clay roads are con-



TYPICAL CROSS SECTIONS SHOWING METHOD OF CONSTRUCTING A SAND-CLAY ROAD, USING TOPSOIL OR OTHER NATURAL MIXTURE.

"W" should be at least 10 feet for single track road and "S" generally not less than 5 feet, for double track, "W" should be not less than 14 feet and "S" not less than 3 feet.

"H" crown, varies from $\frac{1}{2}$" to the foot for level grade, to 1" to the foot for a grade of 5%

FIG. 21.

structed vary over a wide range, and that any general statements regarding costs may be very misleading when applied to a particular case. In general, for a cost estimate to be at all reliable it should be arrived at by considering the following items: (1) grading and preparing the subgrade, (2) excavating and loading surfacing material, (3) hauling surfacing material, (4) mixing and shaping surfacing material.

Table 8 shows the cost of these items for several different sand-clay roads which have been constructed under the supervision of the Office of Public Roads and Rural Engineering and may be of some assistance in preparing estimates of probable cost for similar projects. As a matter of general information it may be stated that in the Southern States the cost of constructing 16-foot sand-clay

FIG. 1.—SAND ROAD BEFORE IMPROVEMENT.

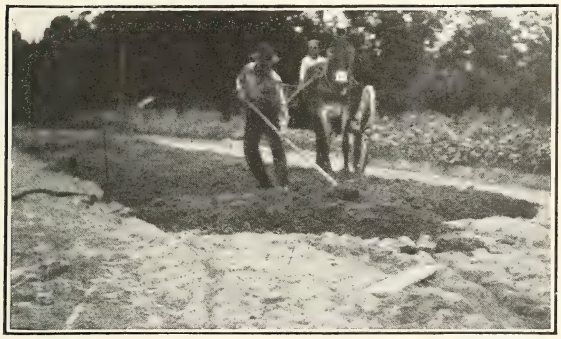


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FIG. 2.—CONSTRUCTING SAND-CLAY ROAD.

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FIG. 3.—SAND-CLAY ROAD; FINISHED AND IN SERVICE.

surfaces, exclusive of grading, usually has ranged between $500 and $1,500 a mile.

TABLE 8.—*Cost of sand-clay roads, exclusive of grading and materials.*

Items.	Project number.							
	1	2	3	4	5	6	7	8
	Brookville, Fla.	Moscow, Miss.	Pearsall, Tex.	San Antonio, Tex.	Gay Head, Mass.	Jackson, N. C.	Tarboro, N. C.	Sayre, Okla.
Length surfaced in miles	0.45	0.78	0.79	1.00	2.19	0.45	2.50	0.75
Width of graded road in feet:								
Cuts	28	30	26	40	22	30	22	28
Fills	20	30	26	26	22	30	22	28
Width surfacing (feet)	16	17	15	16	16	14	18	14
Sand mixture:								
Sand (cubic yards)	660	1,524	.....	.....	1,700	.....	.....	.....
Distance hauled in miles	0.75	1.5	.....	.....	0.125	1.00	.....	.....
Depth applied in inches	3	.....	.....	.....	6	7	.....	.....
Clay mixture:								
Clay (cubic yards)	830	.....	1,556	1,825	2,300	890	2,815	1,383
Distance hauled in miles	0.50	.....	0.19	0.057	0.10	1.00	.....	1.42
Depth applied in inches	7	.....	8	7	6	.....	6	8
Scale of wages per hour:								
Laborers	$0.175	$0.10	$0.12	$0.15	$0.20	$0.12½	$0.08	$0.16
Teams	.50	.25	.30	.34½	.50	.35	.24	.30
Cost:								
Subgrade, per square yard	.031	.003	.0064	.0088	.....	.002	.0018	.0096
Stripping for surfacing material, per cubic yard	.....	.....	.091	.072	.010	.029	.005	.134
Hauling sand, per cubic yard	.425	.49	.....	} .286	.223	.84	.....	.....
Hauling clay, per cubic yard	.374	.....	.914		.344	.....	.255	.567
Spreading material, per cubic yard	.019	.007	.032		.003	.077	.0178	.072
Mixing sand and clay, per square yard	.0035	.006	.0017	.0069	.010	.....	.0024	.007
Final shaping, per square yard	.0035	.....	.0005	.0015	.004	.002	.0022	.....
General expense, per square yard	.0157	.....	.003	.....	.006	.003	.0007	.....
Total cost, per square yard	.198	.105	.121	.089	.082	.233	.036	.187

GRAVEL ROADS.[1]

Roads that are artificially surfaced with gravel, as defined on page 18, or with earthy material in the composition of which gravel predominates, are called gravel roads. This designation covers a variation in type which ranges from roads surfaced with a natural sand-clay mixture containing a considerable percentage of gravel to those having so-called "gravel macadam" surfaces, composed almost wholly of pebbles and constructed in practically the same manner as first-class macadam roads. Gravel roads constitute about one-third the total mileage of surfaced roads in the United States and are confined to no especial section of the country.

In the following discussion of gravel roads it is convenient to consider the subject under the two general heads, "Selection of Gravel" and "Construction Methods."

[1] It is desired to acknowledge the assistance of W. H. Rhodes, U. S. highway engineer, in preparing this discussion, and of J. T. Voshell, J. D. Fauntleroy, J. A. Whitaker, and James C. Wonders, U. S. district engineers, in reading and revising the text.

SELECTION OF GRAVEL.

Ordinarily the selection of gravel for use in road surfacing must be confined to local materials which are or can be made suitable for that purpose. Because of high freight costs it seldom happens that road gravel of even the very best quality is transported by rail a greater distance than about 100 miles from the source of supply, and in the vast majority of cases it is hauled directly from pit to road in wagons. Since the quality of gravel varies to a considerable extent, sometimes in different parts of the same pit, it is essential that local road officials, who frequently are charged with the selection of such material, should have some knowledge of the relation between the physical characteristics of gravel and its wearing qualities when placed in a road surface. While such knowledge can best be gained by actual experience with different kinds of gravel, there are certain general requirements which may be stated for the guidance of the inexperienced. For example, the following excerpt from Bulletin No. 2 of the Michigan State highway department presents in very concise form the characteristics which gravel for road surfacing should possess, in the judgment of the State highway commissioner, in order to meet the Michigan conditions.

> Next to proper drainage, the most important thing in building gravel roads is to secure a good quality of gravel. Authorities have differed as to the requirements of suitable road gravels, most of them, in my opinion, placing too much stress on the immediate packing qualities. Indeed, the average township commissioner and farmers generally have become so imbued with the idea that it is necessary to use a gravel that will pack quickly that they have almost lost sight of the fact that the only thing which makes a gravel road better than an earth road is the pebbles, real stones, that it contains and is dependent upon to bear up traffic and resist wear.
>
> The most common material sought after for the binder in gravel roads is clay. But, considering all kinds of weather, it is probably the poorest cementing material we have. If present, much in excess of 10 per cent of the mass, it will make mud whenever there is a prolonged wet spell, and especially when frost is coming out of the ground in the spring. Ideal clay gravels contain only enough clay to coat the pebbles, with no free lumps. Such gravels are excellent for the first layer on sandy soils, but sand gravels are much better for the first layer on clay and loamy soils.
>
> Gravels that come from the pit with the pebbles cemented together, even though they contain no clay, will recement in the road and become harder than they were in the pit. Tests of specimens of this kind always show that there is much lime present and usually some iron, both of which are excellent cementing materials. Briefly, the experience of the State highway department warrants the statement that there are few, if any, bank gravels in Michigan that do not contain enough limestone and other soft pebbles which grind up under traffic to furnish sufficient binder to cause them to consolidate in a few months' time, if separated from the surplus sand and earth, and properly treated after applying to the road.
>
> In accordance with these suggestions, gravels are considered valuable for road purposes in the following order:

(1) Almost in direct proportion to the percentage of pebbles constituting the mass.

(2) In direct proportion to the value as road metal of the rock fragments constituting the pebbles.

(3) In direct proportion to the value as a cementing material under all conditions of weather, of the finer particles of earthy matter constituting the filler or binder.

Since Michigan is one of the leading States in mileage of roads surfaced with gravel, the experience of the State highway department, as stated in the paragraphs quoted above, should be of considerable value to road officials in other localities, especially where the gravel deposits are principally of glacial origin, as is the case in Michigan. But in many sections of the United States the gravel deposits contain practically no fragments of limestone or other soft rock which might pound up under traffic and serve as a binder to hold the larger particles together, and under such conditions clay or a sand-clay mixture usually must be depended upon to perform this office.

In general, the physical characteristics of gravel which determine its suitability for use in surfacing a road are:

(1) The durability of the pebbles or rock fragments, (2) the quality of the binder, (3) the grading of the pebbles, and (4) the proportion in which the binder material is present. While the influence each of these factors should exert in fixing the selection of gravel for a particular road depends upon local conditions and necessarily is a question for individual judgment to decide, nevertheless a few points in connection with each factor that may aid materially in reaching a decision will be summarized in the following paragraphs.

DURABILITY OF PEBBLES.

The principal qualities which determine the durability of pebbles or stone of any kind when placed in a road surface are hardness, toughness, and resistance to wear. The extent to which pebbles possess these qualities depends very largely on the character of the parent stone from which they were originally produced and accordingly varies over a wide range. Since nearly all gravel deposits contain pebbles which have been formed from many different kinds of stone, it has not been considered practicable to apply the ordinary laboratory tests[1] for determining hardness, toughness, and per cent of wear to gravel, and the matter of comparing these qualities, as possessed by the pebbles from different gravel deposits, usually depends on visual inspection. Not infrequently a very casual inspection will reveal which deposit, among a great number, contains

[1] U. S. Department of Agriculture Bulletin No. 347, "Methods for the Determination of the Physical Properties of Road-Building Rock."

the largest percentage of hard durable pebbles. There are comparatively few cases where this point can not be determined with sufficient accuracy by sorting out the pebbles contained in representative samples from the different deposits, testing the various kinds with a hand hammer, and determining the relative proportions in which the more durable materials are present in the sample by means of a weighing device.

Ordinarily the most durable pebbles which occur in gravel deposits are those composed of either quartzite or chert, though many deposits contain fragments of limestone or trap rock, either of which may make an excellent road-surfacing material. For example, the so-called "blue gravel" which occurs in certain sections of the country usually is composed largely of trap-rock fragments and generally ranks high as a road material. While limestone pebbles are less resistant to wear than those of trap rock, they possess the advantage of a relatively high cementing value and their presence in gravel may aid greatly in securing a well-bonded surface without an excess of clay.

The pebbles which are least durable but very prevalent in gravel deposits are those composed of sandstone. As a rule, such pebbles are lacking greatly in toughness and will shatter under traffic. Gravel deposits also may contain a high percentage of partially disintegrated pebbles which are even less durable than sandstone. "Bastard granite" is a common example of partially disintegrated rock, and not infrequently it happens that gravel deposits contain a high percentage of this material. Partially disintegrated chert is found occasionally in gravels, but as such material possesses a relatively high cementing value, its presence in small proportion may be an advantage rather than a detriment to gravel deposits.

THE BINDER.

No matter how durable may be the pebbles contained in a given gravel deposit, they can not be used successfully in a road surface unless they can be well bonded together so as to present a combined resistance to the disturbing action of traffic. To accomplish this bond requires that the gravel contain some cementing or binding agent such as iron oxide, carbonate of lime, or clay. As already explained, certain pebbles, such as those composed of limestone, possess the property of becoming firmly bonded together by virtue of their own cementing value.

The principal cementing agent, or binder, present in most gravel deposits is clay, and in case of deposits which do not carry sufficient binder, clay usually is the material added to correct the deficiency.

While there are many exceptions to this rule, it is sufficiently general to warrant treating as special cases those deposits in which the binder is not clay.

The suitability of clay for use as a binder for a gravel road surface depends on exactly the same characteristics as its suitability for use in sand-clay construction (see pp. 39 et seq.). That is, a quality of clay which could be used satisfactorily in a sand-clay surface also should make a satisfactory binder for a gravel surface, provided it is used in proper proportion and is properly mixed with sand.

Where the binder consists of some material other than clay its efficiency usually may be tested by observing an exposed bank of the gravel deposit. If the binder is of satisfactory quality, the gravel should be capable of standing on a practically vertical slope and nearly always will contain many lumps composed of numerous pebbles cemented together with the binder. These characteristics are especially noticeable in the case of gravel deposits in which the binder consists essentially of iron oxide, as in some deposits found in New Jersey, Mississippi, and the lake basins of the West.

GRADING AND PROPORTIONS.

For gravel to make a satisfactory road surface, the stone particles should be graded in size so that the amount of binder required will be reduced to a minimum. The reason for this is that the binder usually is much less resistant to wear than the stone particles, and therefore it is desirable that the latter form as large a part of the wearing surface as is practicable. Most gravel deposits as they occur in nature satisfy this requirement in so far as grading of the pebbles is concerned, but they nearly always contain pebbles of a size larger than it is desirable to incorporate in a road surface. Natural deposits also not infrequently contain too large a proportion of sand or clay to produce satisfactory results. It is desirable, therefore, that specifications covering gravel for use in road construction should limit the proportions in which the fine and coarse materials shall be present and a maximum limiting size for the pebbles, as well as definite requirements regarding the quality of the pebbles and of the binder.

Table 9 shows the results of a number of tests made by the Office of Public Roads and Rural Engineering on gravel obtained from various parts of the country, with comments as to the suitability of the different samples for use in road surfacing. The comments are based on observation of existing gravel roads constructed of similar materials and are believed to be well grounded.

TABLE 9.—*Tests on gravel made to determine its suitability for use in gravel-road construction.*

Source of material.	Composition of material.	Mechanical analysis (by weight).																Cementing value.			Remarks on suitability for use in gravel-road construction.
		Per cent retained on sieve No.—							Total per cent passing—	Per cent retained on sieve No.—								Total per cent passing—	On material—			
		1½	1¼	1	¾	½	¼	⅛	⅛	10	20	30	40	50	80	100	200	200	Over ⅛.	Under ⅛.	As received.	
Aiken County, S. C.	Quartz with sand	....	....	....	....	0.6	7.9	21.2	78.8	27.9	53.8	66.9	72.3	78.8	85.6	86.4	90.2	9.8	Good	Good	Good	10 to 15 per cent of ¾ to 1½ inch material should be added.
Bexar County, Tex.	Limestone gravel with large amount of calcareous sand and ferruginous clay.	3.7	6.1	8.4	12.8	23.9	43.4	53.0	47.0	54.6	57.2	59.2	61.0	66.0	71.4	72.4	74.4	25.6	Good	Excellent	Excellent	Test indicates that material contains too much sand and clay.
Jackson County, Oreg.	Weathered rhyolite with sand and ferruginous clay.	3.6	3.6	7.2	14.1	28.2	57.3	68.7	31.3	72.0	76.4	81.6	83.5	86.0	88.5	89.3	89.8	10.2	Excellent	Excellent	Excellent	This material should prove satisfactory.
Spotsylvania County, Va.	Quartz fragments with great amount of quartz sand and siliceous clay.	....	3.9	8.1	25.1	38.2	54.8	64.8	35.2	67.9	75.6	80.1	82.4	84.9	86.9	87.1	89.8	10.2	Low	Excellent	Good	Do.
Fairfax County, Va.	Fragments of quartz and sandstone with quartz sand and highly plastic ferruginous clay.	17.0	21.1	31.1	35.2	44.4	57.3	56.2	43.8	57.4	61.4	65.3	67.3	70.2	73.0	74.0	74.7	25.3	Good	No test	Very good	This sample contains too much fine material.
Do	Rounded fragments of quartz and sandstone with small amount of quartz sand and ferruginous clay.	27.6	40.2	48.0	56.8	64.0	67.0	70.5	29.5	71.2	73.2	75.2	78.0	81.0	83.3	83.9	84.7	15.3	Good	No test	Very good.	This material should prove satisfactory.
Comal County, Tex.	Limestone with some chert, much calcareous sand and ferruginous clay.	8.1	8.1	15.6	22.4	39.0	62.9	71.7	28.3	73.1	75.1	76.1	77.0	78.8	84.3	85.1	87.8	12.2	Good	Excellent	Good	Do.

Bennington County, Vt.	Rounded fragments of quartz, limestone, and quartzite with a small amount of coarse sand.	9.7	19.9	33.4	51.3	71.7	80.4	84.7	15.3	86.0	91.1	94.8	96.1	97.0	97.7	97.9	98.8	1.2	Fair.....	Good.....	Fair.....	Sample contains too large a proportion of material over ¼ inch, and does not contain sufficient binding material.
Do.....	Fragments of quartz, granite, and schist with large amount of coarse sand.	....	....	3.6	8.4	19.9	42.9	65.3	34.7	74.0	92.1	96.0	96.9	97.7	98.2	98.3	98.6	1.4	Low.....	Fair.....	Fair.....	Does not contain sufficient binding material.
Fond du Lac County, Wis.	Large fragments of dolomite with large amount of calcareous sand.	12.6	18.9	26.2	37.4	48.0	62.4	72.5	27.5	75.5	83.8	88.0	90.0	92.0	94.0	94.5	94.6	5.4	Very good.	Good.....	Good.....	Should prove satisfactory under light traffic.
Yazoo County, Miss.	Rounded fragments of chert with large proportion of sand and clay.	7.5	8.7	17.9	33.8	45.0	56.7	63.3	36.7	65.0	67.8	70.4	73.7	82.4	86.0	86.2	86.4	13.6	Fair.....	Excellent.	Good.....	This material should prove satisfactory.
Jackson County, Miss.	Fragments of chert and quartz with sand and ferruginous clay.	....	....	....	1.9	3.8	7.9	10.8	89.2	11.8	17.9	36.0	61.0	86.0	91.8	92.0	93.0	7.0	No test....	Excellent.	Excellent.	The quantity of sand should be reduced by about 30 per cent.
Franklin County, Mo.	Angular fragments of chert and rounded sandstone pebbles with quartz sand and ferruginous clay.	....	2.2	6.8	14.6	27.2	41.5	53.2	46.8	56.4	65.5	73.5	79.2	83.6	87.2	88.1	90.2	9.8	Good.....	Excellent.	Excellent.	The proportion of sand is too high and the grading is not good.
Do.....	.....do.....	....	....	....	.9	8.8	29.2	46.1	54.0	51.5	68.3	81.4	89.4	94.0	96.2	96.6	97.8	2.2	Good.....	Excellent.	Excellent.	This material should prove satisfactory.
Yellowstone County Mont.	Rounded fragments of granite, rhyolite, quartzite, and chert with fine quartz sand.	24.0	32.3	41.6	55.3	69.3	77.3	79.2	20.8	79.6	79.9	81.2	84.0	92.0	98.1	98.8	99.9	0.1	Good.....	Excellent.	Excellent.	Do.
Denver County, Colo.	Rounded fragments of basalt, andesite, and granite with sand and clay.	29.4	36.1	43.9	50.0	58.5	66.8	72.4	27.6	74.0	80.6	84.5	86.7	89.1	91.4	92.0	93.3	6.7	Excellent.	Excellent.	Excellent.	Do.
Pickens County, Ala.	Rounded fragments of chert with quartz sand and ferruginous clay.	....	....	3.7	11.1	28.4	47.8	57.3	42.7	59.3	68.5	76.5	79.8	84.1	90.5	91.2	92.6	7.4	Fair.....	Very good.	Good.....	Probably satisfactory, although the proportion of sand is high.
Comal County, Tex.	Limestone with some chert, much calcareous sand and ferruginous clay.	15.8	21.1	26.8	34.5	45.4	62.1	72.8	27.2	75.8	82.0	84.9	86.3	87.9	89.2	89.5	90.5	9.5	Good.....	Excellent.	Very good.	This material should prove satisfactory.

In general, it has been found that satisfactory gravel will conform to the following limits as to percentages of fine and coarse material:

(1) Material retained on a ¼-inch sieve, 55 to 75 per cent.

(2) Material retained on a ¾-inch sieve, not less than 15 per cent.

(3) Material (clay) passing a 200-mesh sieve for the surface course, 8 to 15 per cent.

(4) Material (clay) passing a 200-mesh sieve for the foundation course, 10 to 15 per cent.

The sand content should be at least twice as great as the clay content; and the sand and clay, when thoroughly mixed, should be sufficient to fill the voids between the larger gravel particles. The percentages given above usually will conform to this requirement. The maximum limiting size for the pebbles ordinarily should be from 2½ to 3 inches, because where larger particles are permitted in the surface the rate of wear is made unequal, and it is more difficult to maintain a satisfactory bond between the different particles.

A satisfactory mechanical analysis of a gravel sample along the lines indicated above frequently may be made in the field by first separating the coarse material from the fine by means of a ¼-inch mesh screen and then washing the clay out of the fine material, as described in the discussion of sand-clay roads. Both the coarse and fine materials obtained from the sample may be further separated into different sizes by means of suitable screens if, for any reason, this is desirable in making the test.

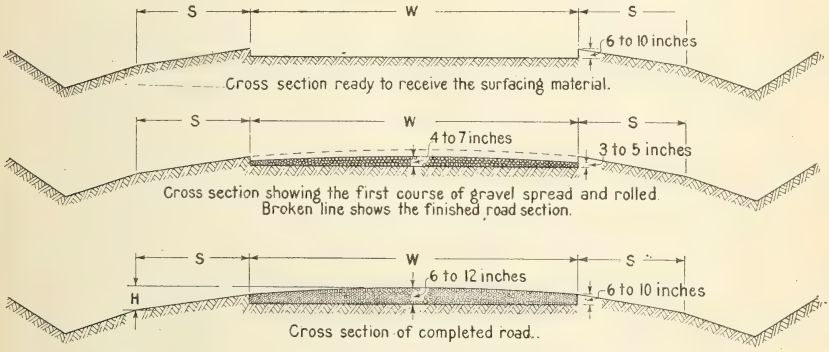
It happens very often that a mechanical analysis will indicate the necessity of screening the natural gravel to remove a portion of either the fine or coarse material so as to keep the proportions within the limits mentioned above. It is also necessary sometimes to wash the gravel in order to remove excessive clay, but this process is expensive, and it is generally practicable to secure the desired results by screening. When the analysis shows the desirability of adding clay or sand to the gravel, this should be done as the surface is constructed by spreading a uniform layer of the needed material over each course of gravel and mixing it thoroughly into the mass by harrowing.

CONSTRUCTION METHODS.

Figure 22 shows a typical cross section for a gravel-road surface and indicates the customary steps involved in the construction of such a surface. The limiting thicknesses shown on this cross section are by no means followed universally, but are believed to represent the best current practice. The minimum thickness shown is supposed to be employed where the traffic is light and the subgrade is uniformly stable, while the maximum thickness is adapted for opposite conditions. Perhaps the most usual compacted thickness of surface

is 8 inches at the center and 6 inches at the edges. The difference in thickness between the edges and the center is effected by making the crown of the subgrade flatter than that of the surface.

The construction of a gravel road usually is divided into two entirely distinct classes of work. The work of grading and preparing the subgrade falls into one class, and that of hauling, spreading, and compacting the gravel into the other. The first class of work has been discussed at considerable length in connection with earth and sand-clay roads, but since it is desired to emphasize certain features of subgrade preparation that are of increased importance



TYPICAL CROSS SECTIONS SHOWING METHOD OF CONSTRUCTING A GRAVEL ROAD

"W" should be at least 10 feet for single track roadway and "S" generally not less than 5 feet; for double track, "W" should be not less than 14 feet and "S" not less than 3 feet.
"H", crown, varies from $\frac{1}{2}$ inch per foot for level grade, to 1 inch per foot for a grade of 5%.

FIG. 22.

in connection with gravel road construction, both classes of work will be considered in the following discussion.

PREPARATION OF THE SUBGRADE.

In grading the roadbed and preparing the subgrade for a gravel surface, all of the precautions previously noted as applying to similar features of earth and sand-clay road construction should, of course, be observed. It should be borne in mind also that the more expensive a road surface, the greater should be the care exercised to prevent it from being damaged through settlement or upheaval of the subgrade, and the greater should be the accuracy with which the subgrade is constructed, so that no unnecessary surfacing material may be required to correct irregularities in grade and cross section. No matter what the soil conditions may be, the subgrade for a gravel road surface, when completed, should conform closely in grade and cross section to the requirements of the plans and should present

an even, uniform appearance. Also, it should be as firm and unyielding as the conditions will permit.

Some of the most important details requiring careful attention in preparing the subgrade, and which are perhaps most frequently overlooked, are (1) backfilling culvert trenches so as to prevent subsequent settlement, (2) exclusion of vegetable matter from fills, (3) provision for draining wet-weather springs which occur in the subgrade, and (4) the matter of thoroughly loosening and distributing the materials contained in old road crusts. These details are treated briefly in another part of this bulletin.

After the roadbed has been graded and drained properly, and the details mentioned above have received proper attention, the work of preparing the subgrade consists simply in forming a trench, as shown in figure 22, to receive the gravel surface. The trench may be formed largely with a grading machine, the operation of which is described on page 21, but the final shaping should be effected by means of picks and shovels and rolling. It is customary to provide grade stakes at intervals of about 50 feet, to serve as a guide for the pick and shovel work, and where extreme accuracy is desired cords may be stretched between the stakes to insure that the subgrade conforms to the required grade throughout. The rolling is done ordinarily with a power roller weighing about 10 tons.

In order that the subgrade may be well drained during the process of spreading and compacting the gravel it is frequently necessary to provide shoulder drains at comparatively short intervals. Such drains are constructed by opening small ditches through the shoulders and partially filling them with gravel. (See specification on page 66.)

THE GRAVEL SURFACE.

The principal precautions to observe in constructing a gravel road surface, after the subgrade is prepared, may be commented upon briefly as follows:

(1) The gravel should be delivered on the work in wagons or cars especially adapted for spreading each load uniformly over that part of the subgrade for which it is intended. Where loads are dumped all in one spot and spread later with shovels, as is done frequently, it is very difficult to secure uniform density of the surface crust by subsequent harrowing and rolling. The spots where the loads are dumped nearly always will be more densely compacted than the areas between, and, as a result, uneven settlement will develop soon.

(2) The gravel should be spread in two or more courses, and the thickness of the different courses should be approximately the same, except that the first course may be made somewhat thicker than the

succeeding courses, because, in general, a thicker layer of gravel may be compacted on the subgrade than when spread over a layer of gravel already compacted. It usually is impracticable to have the compacted thickness of any course greater than about 5 inches, and quite frequently 3 or 4 inches is as much as can be compacted satisfactorily at one time.

(3) After each course of gravel is spread it should be harrowed with a tooth harrow until the various sizes of particles and the binder or cementing material are distributed thoroughly through the mass. Then it should be compacted by rolling with a power roller weighing about 10 tons, or by means of traffic. Where a roller is employed the rolling should be continued until the particles of gravel are all well bonded together and the surface presents a smooth, uniform appearance. When completed, the surface of each course should be so firm and unyielding that it will not be disturbed in any way by subsequent traffic.

(4) Where it is necessary to add sand or clay to the gravel in order to fill the voids it should be done after each course is spread and before it is harrowed, except that with some kinds of gravel it may be permissible to add a limited amount of fine material to the surface of the top course after the harrowing is completed and the rolling is in progress.

(5) Where the binder consists of some material other than clay, it may be desirable to sprinkle each course with water while it is being rolled, and even where clay is used as a binder a small amount of sprinkling may be necessary in dry weather in order to secure a satisfactory bond. The sprinkling should be done uniformly and in such quantities as not to wash the fine material out from the gravel or to soften the subgrade.

(6) When the road surface is complete it should be uniform in grade and cross section. If depressions occur under the roller they should be corrected by adding gravel and continuing the rolling, and this should be kept up until no depressions or appreciable waves are produced by the roller in moving back and forth over the surface.

(7) After the road is opened to traffic, it should be watched very carefully for several months and all defects which develop should be corrected immediately. The work of maintaining the road until the surface no longer "picks up" or ravels under traffic should be considered an essential feature of the construction. When traffic is depended upon to compact the gravel, much dragging is necessary in order to secure a smooth, well-bonded surface. In fact, the cost of dragging, under such conditions, frequently may exceed the cost of securing a well-bonded surface by means of rolling.

Plate V, figures 1, 2, and 3, illustrates the different kinds of work involved in gravel-road construction.

The construction method described above is modified quite frequently by omitting the subgrade trench and the rolling. The practice followed in many localities is simply to grade up the roadbed and heap gravel along the central portion. Traffic is then depended upon to spread and compact the gravel and produce a uniform surface. While some of the roads constructed in this way are great improvements over the original earth roads they nearly always are crowned too much for comfortable driving, and seldom wear as well as when the more careful method of construction is followed. It is believed, therefore, that in the long run it pays to employ a trenched subgrade and to compact the surface by rolling, though a possible exception to the economy of a trenched subgrade may exist where good gravel may be obtained very cheap. In this case it may be cheaper to surface the entire roadway than to incur the additional expense of trenching and constructing earth shoulders.

COST OF GRAVEL ROADS.

In estimating the cost of a gravel road it is necessary to consider (1) the cost of grading and preparing the subgrade, (2) the purchase price of the gravel it is proposed to use, (3) the cost of delivering the gravel on the road, and (4) the cost of spreading and compacting the gravel.

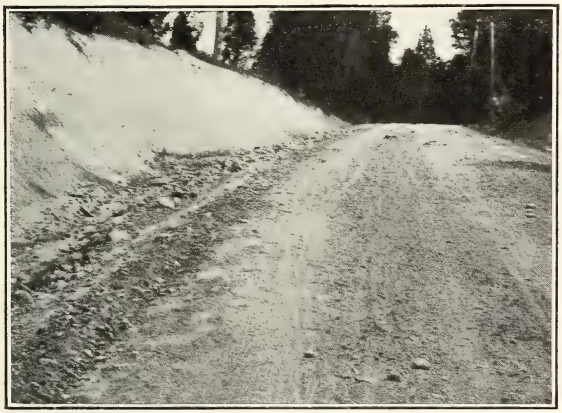
The cost of grading has been discussed in connection with earth roads and need not be considered here. But it should be borne in mind that the cost of preparing the subgrade, after the rough grading is complete, depends to a very considerable extent upon the degree of care exercised in doing the latter work. The character of the soil composing the roadbed also may be an important factor in determining the cost of preparing the subgrade, especially if any considerable period of time elapses after the completion of the rough grading before the subgrade is prepared. Some soils remain loose indefinitely and are worked into proper shape easily, while others may become hard and compact in a very short time after being placed in a roadbed.

Where a road has been graded previously with moderate care and has not settled out of shape or been allowed to erode, and where the price of labor is about 20 cents per hour and of teams about 40 cents per hour, the cost of preparing a subgrade for a gravel road surface varies about as follows:

	Cents per square yard.
Light loam soil	1½ to 2
Light clay soil, freshly graded	2 to 4
Stiff clay soil, freshly graded	3 to 5
Stiff clay soil, thoroughly compacted	5 to 8

OPRRE13573

FIG. 1.—CONSTRUCTING A GRAVEL ROAD SURFACE IN TWO COURSES.



OPRRE11129

FIG. 2.—COMPLETED GRAVEL ROAD IN USE.

OPRRE12780

FIG. 3.—GRAVEL PIT IN ALEXANDRIA COUNTY, VA.

These costs include all necessary rolling for compacting the subgrade.

The two succeeding factors, purchase price of gravel and cost of delivering the gravel on the road, evidently are dependent to a very great extent on local conditions, and their influence on the cost of a given road can not be determined except by a study of those conditions. The following data are intended to serve only as an aid in making the necessary study.

(*a*) A cubic yard of loose gravel ordinarily weighs between 2,700 pounds and 3,300 pounds, the average weight being about 3,000 pounds.

(*b*) Loose gravel will shrink from 20 per cent to 30 per cent in volume when compacted in a road surface. In determining the loose volume of gravel required for a given project, it is customary to compute the compacted volume and add at least one-third.

(*c*) The average cost of loading pit gravel by hand into wagons is about 20 cents per cubic yard. Where the amount of work to be done is sufficient to warrant the installation of a steam shovel or the construction of a special scaffold so that wheeled scrapers may be used for loading, the cost of this work may be reduced, sometimes 50 per cent or more.

(*d*) The cost of screening gravel varies greatly according to the character of the pit-run material and the kind of screening equipment employed. Hand screening usually costs from 25 cents to 48 cents per cubic yard, while with a properly arranged mechanical screen the cost should not often exceed 15 to 20 cents per cubic yard.

(*e*) The cost of hauling depends on the equipment used and the condition of the road over which the hauling is done. With teams at 50 cents per hour and the roads such that 2 tons may be hauled at a load the average cost for hauling is about 25 cents per ton-mile, or 37½ cents per cubicyard-mile.

The fourth factor to consider, cost of spreading and compacting the gravel, depends on the character of the gravel and of the equipment, as well as on the cost of labor. On five gravel-road projects recently completed under the supervision of the Office of Public Roads and Rural Engineering the cost of spreading the gravel ranged from about 3 cents to about 8 cents per cubic yard. The average cost was about 6½ cents per cubic yard, and the average cost of labor was about 20 cents per hour. The wagons used in all cases were dumped directly upon the subgrade and were designed to spread the material to a considerable extent while it was being dumped.

The cost of rolling the gravel on the above five projects ranged from slightly less than ½ cent per square yard of surface to about 1 cent per square yard, and the average cost was about 0.6 cent

per square yard. These costs include labor only, and if fuel for the roller and depreciation were considered, the average cost probably would approximate 1½ cents per square yard.

ROAD MAINTENANCE.

METHODS OF MAINTENANCE.

As soon as a road is constructed, the action of traffic and the weather begin to destroy it, and to counterbalance the effects of these deteriorating influences it is necessary to institute some system of maintenance. There are two common ways of maintaining a road. One is to make periodic repairs or renewals after sections of the road have been practically destroyed; the other is to employ a system of continuous maintenance under which all injuries to the road are repaired as fast as they occur. For the types of roads which have been discussed the system of continuous maintenance is much more preferable from practically every standpoint, and that system alone will be discussed here.

THE ROAD DRAG.[1]

The road drag is a simple and inexpensive device for maintaining certain types of roads which, when wet, become rutted under traffic but which become firm on drying out. It is useful also in producing a smooth and uniform surface on newly constructed roads of earth, earthy gravel, or any similar material. Figures 23 and 24 show typical designs for road drags made, respectively, of a split log and of sawed timber, and drags made in accordance with either design may be operated with two horses.

Properly used at the right time the drag performs four distinct functions: first, by moving at an angle with the traveled way, it tends to produce or preserve a crowned cross section; second, if used when the surface is comparatively soft, it tends to reduce irregularities in the road, by moving material from points which are relatively high to those which are relatively low; third, when used after a rain it accelerates the drying out of the road by spreading out puddles of water and thus exposing a greater area to evaporation; fourth, if the surface material is in a slightly plastic state, dragging smears over and partially seals the so-called pores which naturally occur in earthy material, and thus makes the road surface more nearly impervious to water.

To obtain the best results dragging should be done only when the surface of the road is sufficiently moist for the material moved by the

[1] See Farmers' Bulletin No. 597, "The Road Drag and How it is Used."

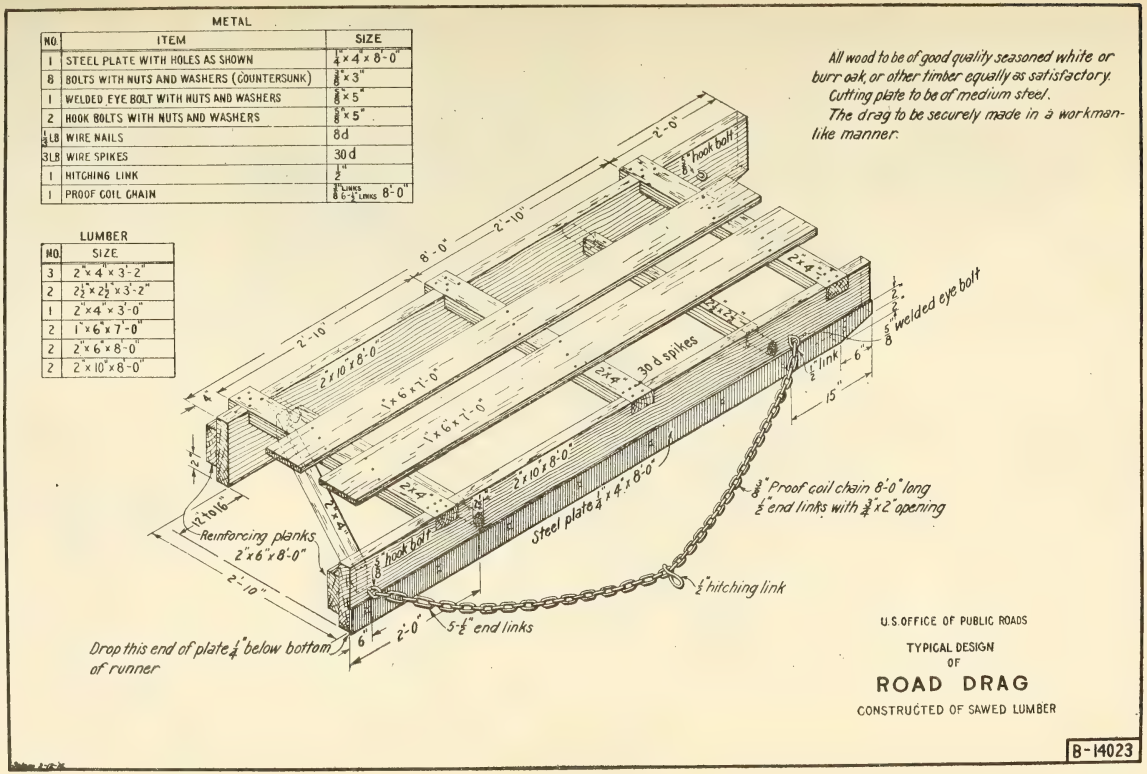

METAL
NO. | ITEM | SIZE
1 | STEEL PLATE WITH HOLES AS SHOWN | 1/4 × 4 × 8'-0"
8 | BOLTS WITH NUTS AND WASHERS (COUNTERSUNK) | 3/8" × 3"
1 | WELDED EYE BOLT WITH NUTS AND WASHERS | 5/8" × 5"
2 | HOOK BOLTS WITH NUTS AND WASHERS | 5/8" × 5"
1/4 LB | WIRE NAILS | 8d
3 LB | WIRE SPIKES | 30d
1 | HITCHING LINK | 1/2"
1 | PROOF COIL CHAIN | 3/4" LINKS 8'-0" 5/8 6-1/2" LINKS
LUMBER
NO. | SIZE
3 | 2" × 4" × 3'-2"
2 | 2 1/2" × 2 1/2" × 3'-2"
1 | 2" × 4" × 3'-0"
2 | 1" × 6" × 7'-0"
2 | 2" × 6" × 8'-0"
2 | 2" × 10" × 8'-0"
All wood to be of good quality seasoned white or burr oak, or other timber equally as satisfactory.
Cutting plate to be of medium steel.
The drag to be securely made in a workmanlike manner.
2'-0"
2'-10"
8'-0"
2'-10"
5/8" hook bolt
2×4
2×10×8'-0"
1×6×7'-0"
1×6×7'-0"
2×4
30 d spikes
2×4
2×10×8'-0"
2×4
5/8" hook bolt
Steel plate 1/4"×4'×8'-0"
5/8" welded eye bolt
1/2" link
6"
15"
3/4" Proof coil chain 8'-0" long
5/8" end links with 3/4"×2" opening
1/2" hitching link
5-5/8" end links
2'-0"
6"
12"
12"
16"
Reinforcing planks
2"×6"×8'-0"
2'-10"
Drop this end of plate 1/4" below bottom of runner
U.S. OFFICE OF PUBLIC ROADS
TYPICAL DESIGN
OF
ROAD DRAG
CONSTRUCTED OF SAWED LUMBER
B-14023

FIG. 23.

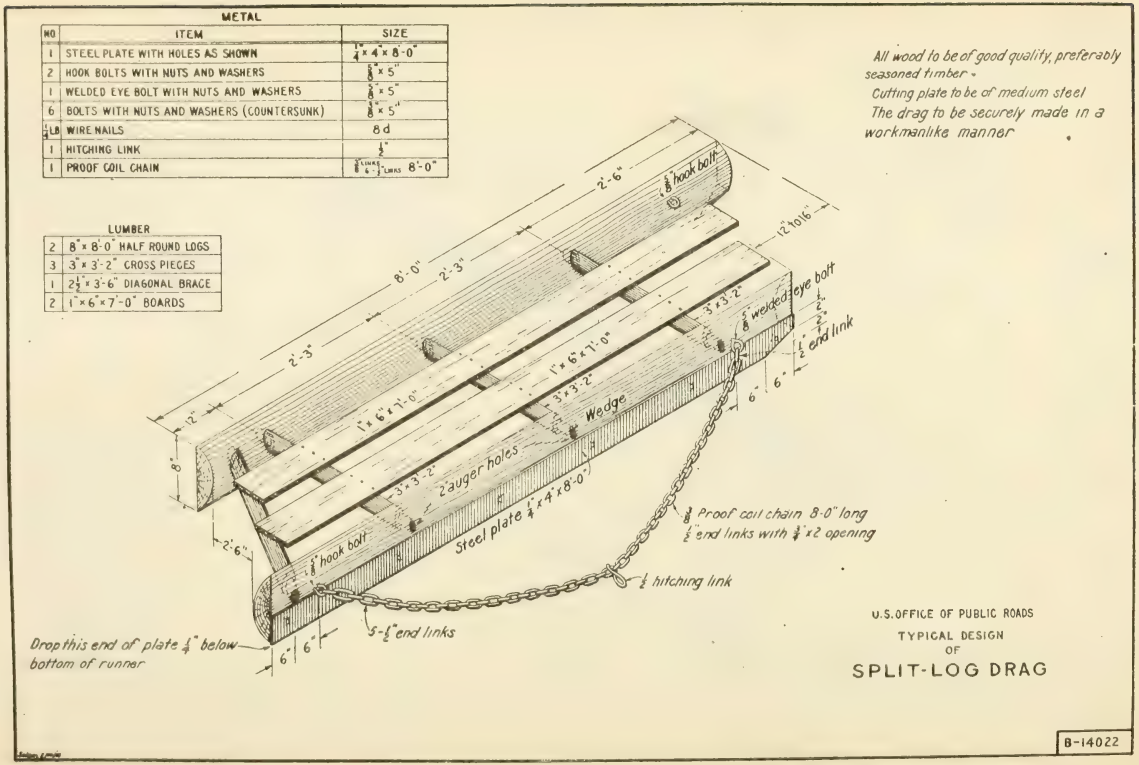

METAL
NO | ITEM | SIZE
1 | STEEL PLATE WITH HOLES AS SHOWN | 1/4" x 4" x 8'-0"
2 | HOOK BOLTS WITH NUTS AND WASHERS | 5/8" x 5"
1 | WELDED EYE BOLT WITH NUTS AND WASHERS | 5/8" x 5"
6 | BOLTS WITH NUTS AND WASHERS (COUNTERSUNK) | 5/8" x 5"
1/4 LB | WIRE NAILS | 8d
1 | HITCHING LINK | 1"
1 | PROOF COIL CHAIN | 5/8" LINKS 6-1" LINKS 8'-0"
LUMBER
2 | 8" x 8'-0" HALF ROUND LOGS
3 | 3" x 3'-2" CROSS PIECES
1 | 2 1/2" x 3'-6" DIAGONAL BRACE
2 | 1" x 6" x 7'-0" BOARDS
All wood to be of good quality, preferably seasoned timber.
Cutting plate to be of medium steel
The drag to be securely made in a workmanlike manner.
5/8" hook bolt
2'-6"
8'-0"
2'-3"
12" to 16"
5/8" welded eye bolt
1/2" end link
1" x 6" x 7'-0"
3" x 3" x 2'-0"
Wedge
2 auger holes
Steel plate 1/4" x 4" x 8'-0"
5/8" Proof coil chain 8'-0" long
5/8" end links with 1/4" x 2 opening
1" hitching link
5-5/8" end links
Drop this end of plate 1/4" below bottom of runner
U.S. OFFICE OF PUBLIC ROADS
TYPICAL DESIGN
OF
SPLIT-LOG DRAG
B-14022

FIG. 24.

drag to compact readily after it is moved, but not sufficiently wet for traffic following the drag to produce mud.

The principal factor in successfully operating a properly constructed road drag, provided the condition of the road is favorable, is skill on the part of the operator. Such skill can be obtained only by intelligent experience, and no rules can be laid down which would enable an inexperienced operator to produce first-class results.

Under ordinary circumstances the position of the hitching link on the draw chain should be such that the runners will make an angle of 60° to 75° with the center line of the road, or, in other words, a skew angle of from 15° to 30°. But when dragging immediately over the ruts, or down the center of the road after the sides have been dragged, it may be found advantageous to place the hitching link at the center of the chain and run the drag without skew. An intelligent operator will learn quickly to adjust such details as this, as well as to shift his weight while riding upon the drag in order to make it cut where cutting is desirable, and deposit material where material is needed.

MAKING REPAIRS.

If roads of such types as have been discussed are to be maintained properly, they must frequently receive other attention than mere dragging. The side ditches should be kept open and free from vegetation, the cross drains and culverts maintained in proper condition, and worn places in the surface repaired as fast as they develop.

The material used in repairing the surface should be the same as that composing the surface and should be put on in such quantity and manner that after it is compacted the surface will be uniform and continuous. Much time and labor can be saved by making repairs as soon as needed, because when a bad place once develops in a road it generally will spread very rapidly until proper steps are taken to correct it.

COST OF MAINTENANCE.

There are not sufficient cost data available at present to warrant any very definite statements as to the cost of maintenance, but when roads can be maintained largely by use of the drag, as usually is the case with the simpler types of construction, the cost ordinarily is very small. Accurate data kept by a representative of the Office of Public Roads for road maintenance in Bennington County, Vt., during 1912 and 1913 showed that under favorable conditions a road could be dragged at the rate of about 1 mile per hour. This was where the road was comparatively well shaped and only one trip in each direction was necessary. Where more trips of the drag were re-

quired the rate was, of course, correspondingly diminished. In this county teams with drivers cost from $3.50 to $5 per working day of from 8 to 10 hours, and the cost per mile for dragging a road in one trip showed a corresponding variation. The number of draggings necessary per year varied over a wide range and depended on the length of time the road had been constructed and the character of the material composing the surface.

The average cost per mile of dragging an earth road 8 miles long in Alexandria County, Va., during 1911 and 1912 was $1.25 for each dragging, which included an average of three round trips, and the total number of draggings necessary to maintain the road in good condition was 24 per year, making the average cost for dragging $30 per mile per year. This road was maintained as an experiment by the Office of Public Roads and Rural Engineering.

APPENDIX.

TYPICAL SPECIFICATIONS.[1]

The following specification clauses are intended only as an aid in preparing detailed specifications for contract work and frequently will need to be modified to meet special conditions. The general clauses and the clause covering grading are applicable to the three types of construction which have been discussed in the text, while the subsequent clauses are arranged with especial reference to sand-clay and gravel construction.

In general, all contract road work should be done under the supervision of a competent highway engineer, who, before contractors are invited to submit bids, should prepare specifications covering the work to be undertaken.

Location.—The work referred to in these specifications is to be done on the —— road, beginning at —— and extending in a —— direction through ——— to ——, a distance of —— miles.

Work to be done.—The contractor shall do all clearing and grubbing, make all excavations and embankments, do all shaping and surfacing, construct all drainage structures and other appertaining structures, move all obstructions in the line of the work, and, unless otherwise provided in these specifications, shall furnish all equipment, materials, and labor for the same. In short, the contractor shall build said road in strict accordance with the plans and specifications and shall leave the work in neat and finished condition.

Plans and drawings.—The plans, profiles, cross sections, and drawings on file in the office of —— at —— show the location, profile, details, and dimensions of the work which is to be done, and shall be considered as a part of these specifications. The work shall be constructed according to the above-mentioned plans, profiles, cross sections, and drawings. Any variation therefrom, as may be required by the exigencies of construction, will in all cases be determined by the engineer. On all drawings figured dimensions are to govern in cases of discrepancies between scale and figures.

Grading.—Grading shall include all excavating, filling, borrowing, trimming, picking down, shaping, sloping, and all other work that may be necessary in bringing the road to the required grade, alignment, and cross section; the clearing out of waterways and old culverts; the excavation of all necessary drainage and outlet ditches; the grading of a proper connection with all intersecting highways; the grubbing up and clearing away of all trees, stumps, and bowlders within the lines of the improvement; and the removal of any muck, soft clay,

[1] These specifications were prepared by the Office of Public Roads and Rural Engineering largely for its own use in connection with particular projects.

or spongy material which will not compact under the roller [1] so as to make a firm unyielding subgrade or earth road surface.

All trees, stumps, and roots within the limits of the improvement shall be grubbed up so that no part of them shall be within 6 inches of the surface of the ground or within 18 inches of the surface of the subgrade, except that if they occur in an area to be covered by a fill more than 18 inches in depth they shall be grubbed up or cut off even with the present surface of the ground.

Embankments shall be formed of good sound earth or stone and carried up full width. The material shall be deposited in layers not more than 1 foot in thickness, and each layer shall be rolled [1] until thoroughly compacted with a roller weighing not less than 10 tons. All existing slopes and surfaces of embankments shall be plowed or scarified where additional fill is to be made, in order that the old and new material may bond together. When sufficient material is not available within the right of way to complete the embankments, suitable borrow pits from which the contractor must obtain the necessary material will be designated by the engineer. If there is more material taken from the cuts than is required to construct the embankments, as shown on the plans, the excess material shall be used in uniformly widening the embankments or shall be deposited where the engineer may direct. Where embankments are formed of stone, the material shall be carefully placed so that all large stones shall be well distributed and the interstices shall be completely filled with smaller stone, earth, sand, or gravel, so as to form a solid embankment.

During the work of grading the sides of the road shall be kept lower than the center and the surface maintained in condition for adequate drainage.

The grading of any portion of the road shall be complete before any surfacing material is placed on that portion, and where the plans do not call for any substantial change in the grade of any existing section of the road, the surface shall be completely scarified to a depth of 3 inches or more before the subgrade is prepared.

All excavated material [2] will be classed as earth and rock. Only rock in place which requires blasting for its removal and bowlders of one-half cubic yard or more in volume will be classed as rock excavation.

Materials obtained from excavation and used in embankments will be paid for as excavation only, though the contractor is required to shape and trim the embankments properly. Materials obtained from excavation and used for surfacing will be paid for only once and at the price bid for surfacing material.

Quantities of materials moved in grading will be measured in excavation and the volumes determined by the average end-area method, and no payment will be made for materials excavated outside the slope lines shown on the plans unless the additional excavation is ordered by the engineer.

The contract prices for excavation shall be compensation in full for all the work which is required to be done under the heading "grading," except that an additional allowance at the rate of 1½ cents per cubic yard per 100 feet will be made for all materials of excavation necessarily hauled more than 500 feet. The centers of gravities of cuts and corresponding embankments will be used in determining the length of haul, and if the center of gravity of the

[1] For earth and sand-clay arods the rolling is frequently omitted.

[2] In general it is more satisfactory to classify the materials of excavation and to invite unit-price bids rather than lump-sum bids. However, if unit-price bids are invited it is important that the various quantities be accurately determined in order that the best bid may be selected. If lump-sum bids are desired, omit the following paragraphs.

cut is more than 500 feet from the center of gravity of the corresponding fill, overhaul will be allowed for the entire amount of material in the cut for the actual distance in excess of 500 feet.

Drainage structures.—[Insert specifications for necessary drainage structures.]

SPECIFICATION FOR SAND-CLAY ROAD.

Subgrade.—The graded roadway shall be brought to the elevation, alignment, and cross section indicated for subgrade on the plans, and shall be maintained free from ruts and other depressions until covered with the surfacing material.

Natural sand-clay surfacing.—The engineer will designate suitable places for obtaining natural sand-clay mixtures for surfacing.

All unsuitable material that may overlie the acceptable material shall be stripped off and removed, and this work will be paid for at the unit-price bid for stripping, measured in excavation.

The natural sand-clay mixture shall then be excavated, hauled to the road, and spread. All excavation shall be so conducted that the pits will be left in good and sightly condition, and that, where possible, provision will be made for draining the pits without additional excavation beyond their limits.

Hauling.—The hauling shall be done in wagons of approximately uniform capacity, and the loads shall be dumped at such a distance apart as will give the amount of material required to construct the surface according to the proposed cross section.

Spreading.—The surfacing material shall be immediately spread on the prepared subgrade to such depth that the surface, when compacted, will conform accurately with the profile, alignment, and cross section, as shown on the drawings. All subsequent loads may then be hauled over the surface thus formed.

The construction of the surface shall begin at that point on the road nearest the source of material and be continued from such point. In hauling over the material as deposited, wagons will be required to use the entire width of surfaced roadway so as to compact the whole section as nearly to a uniform density as possible. The teams will not be permitted to follow a single track or to form ruts.

Finishing.—After 500 or 600 feet of roadway have been thus roughly constructed the surface shall be cut up and pulverized to a depth of 2 or 3 inches with a plow or harrow and at the same time the shoulders on each side of the surfaced portion of the road shall, if necessary, be sufficiently loosened to permit of a smooth regular crown being constructed from shoulder to center of road.

When the roadway has been loosened sufficiently, the surface shall be worked with a road grader or drag to the true cross section required by the plans. This operation shall be repeated daily until the entire surface becomes smooth and firm.

Mixing sand clay.—In case the natural sand-clay mixture, as found, does not contain a sufficient percentage of either sand or clay to give a durable surface there shall be spread as much of the deficient material as the engineer may direct, and this shall be thoroughly mixed and incorporated with the material previously spread. In places where a natural mixture is not available suitable amounts of clay or sand shall be hauled, spread, and mixed as directed by the engineer.

The process of mixing may require plowing to a depth of 6 or 8 inches and harrowing with a disk or tooth harrow, and this work may be required in wet weather.

All mixing shall be classed as extra work and shall be paid for at prices bid for force account work.

The completed surface will be paid for by the cubic yard of surfacing material used, measured in excavation. So much of the surfacing material as is necessarily hauled more than —— feet will be classed as sand-clay overhaul and paid for at the price bid for this item.

SPECIFICATION FOR SURFACING A ROAD WITH GRAVEL.

Subgrade.—The subgrade, or that portion of the road upon which the surfacing material is to be laid, shall consist of good sound earth brought to the proper elevation, alignment, and cross section, and shall be rolled until firm and hard. The rolling shall be done with a roller of the macadam type, weighing not less than 10 and not more than 15 tons. Should earth be encountered which will not compact by rolling, so as to be firm and hard, it shall be removed and replaced with suitable material, and that portion of the subgrade shall be again rolled. When the rolling is completed the surface of the subgrade shall conform to the cross section shown on the plans and shall have the proper elevation and alignment and shall be so maintained until the surfacing material is in place. No surfacing material shall be spread on any portion of the road until the subgrade of that portion has been prepared as herein specified.

Shoulders.—During the preparation of the subgrade, and before any surfacing material is placed thereon, shoulders shall be built of the width shown on the cross-section drawings and to a height not less than the edge thickness of the first course of gravel before it is compacted. They shall be true in alignment and shall have the edges next to the subgrade as nearly vertical as the nature of the soil will permit.[1] If intermediate courses are required, the shoulders shall be built up to receive each course in the manner described above for the first course before the material for that course is spread. Before the wearing course is spread, sufficient material shall be added to the shoulders to bring them up level with the surface of the wearing course before it is compacted and so that the shoulder when rolled will have the shape shown on the cross-section drawings. No material which contains weeds, sod, roots, or other perishable matter and which will not compact under the roller shall be placed in the shoulders. The shoulders shall be thoroughly compacted by rolling at the time the wearing course is rolled, and when complete shall be uniformly firm and unyielding and of the required shape.

Should the contractor prefer, he may build the shoulders at one operation before any surfacing material is placed on the subgrade, but if the shoulders are so built they shall be reshaped after each course is rolled and before the succeeding course is spread.

The contract price for shaping the subgrade and shoulders shall be compensation in full for all work directed to be done under the headings "Subgrade" and "Shoulders."

Shoulder drains.—Shoulder drains shall be constructed where indicated on the plans or directed by the engineer and shall be of such depth and length as may be necessary to drain water from the subgrade into the side ditches. The ditches for such drains shall be excavated just before the first course of

[1] If the material composing the shoulders should be so loose that a nearly vertical edge can not be obtained, boards may be staked in line to hold the gravel in place. As soon as the first course of gravel has been spread earth should be placed against the boards and they should be removed before any rolling is done. The general use of these boards is discouraged.

gravel is spread and shall be filled with No. 1 gravel to within 2 inches of the finished surface of the shoulder.

The contract price for shoulder drains shall be compensation in full for constructing them as above specified, except that the No. 1 gravel used shall be paid for by the ton at the price bid for No. 1 gravel in place in the first course.

Gravel surface.—On the subgrade, prepared as herein specified, shall be constructed a gravel surface of the cross section and number of courses shown on the plans, and each course when compacted shall have the thickness indicated on the plans.

Gravel.—The gravel used in this work shall consist of hard durable particles of stone mixed with sand and clay or other bonding material. Not less than 55 per cent nor more than 75 per cent, by weight, of the gravel shall consist of stone particles sufficiently large to be retained on a one-fourth inch mesh screen.

The material passing a one-fourth inch mesh screen shall consist of sand and clay or other bonding material which, when tested in the manner described in Department Bulletin No. 347, "Methods for the Determination of the Physical Properties of Road-building Rock" (p. 15), shall have a cementing value of not less than 50. This material shall not contain more than 33 per cent, by weight, of clay. The material retained on a one-fourth inch mesh screen shall be graded from fine to coarse so that not more than 75 per cent and not less than 25 per cent will pass a three-fourths inch mesh screen.

The gravel for the first course, hereafter designated as "No. 1 gravel," shall not contain any particles which would be retained on a screen having circular openings 2½ inches in diameter. The gravel for the wearing course, hereafter designated as "No. 2 gravel," shall not contain any particles which would be retained on a screen having circular openings 1½ inches in diameter.

Gravel obtained from the pits located at [insert location descriptions of approved gravel pits] will be acceptable under this specification, provided that, if necessary, the gravel shall be screened to remove any excess of either fine or coarse material which it may contain above the limits specified.

First course.—The first course shall consist of a single layer of No. 1 gravel, spread uniformly to such a depth that when compacted it will have the thickness shown on the cross-section drawings. The gravel shall be spread by hand from dumping boards or by dump wagons of a type that will distribute the gravel evenly over that part of the subgrade to be covered by the load or by wagons that will distribute it uniformly over the subgrade in rows containing not more than 1,000 pounds of gravel in a length of 10 feet. In order to secure the required thickness for the course, the contractor shall, if required by the engineer, set wooden guide blocks upon the subgrade at frequent intervals. These blocks shall be about 6 inches square and of a height equal to the required depth of the loose layer, and the gravel shall be spread flush with the tops of the blocks. After the gravel has been spread, as above specified, it shall be harrowed with a tooth harrow until the different-sized particles and the cementing material are evenly distributed through the mass. It shall then be rolled until it is thoroughly compacted and firm. The rolling shall begin at one edge of the course, one rear roller wheel overlapping the shoulder from 2 to 6 inches, and shall progress gradually to the center of the road in such a manner as to insure the uniform compacting of the gravel. The rolling shall then begin at the opposite edge and proceed as above. All irregularities and depressions that may develop shall be corrected immediately by reharrowing and adding No. 1 gravel, and the rolling shall be repeated, so that when the course is completed it shall be well compacted and firm and shall conform to

the required grade and cross section. It shall be so maintained until the second course of gravel has been spread.

Intermediate courses.—When intermediate courses are required, they shall be constructed in a manner exactly similar to that described above for the first course.

Wearing course.—After the first and intermediate courses of gravel have been rolled as specified the earth shoulders shall be built up or reshaped to conform with the finished cross section of the road, and the wearing course, consisting of a single layer of No. 2 gravel, shall be spread uniformly to such a depth that when compacted it will have the thickness shown on the cross-section drawings. The methods specified for spreading, harrowing, rolling, and correcting irregularities and depressions in the first course shall also apply to the wearing course, except that the rolling for the latter shall begin on the shoulder, at least 2 feet from the edge of the gravel.

When the gravel surfacing and shoulders have been rolled until thoroughly compacted and have been brought to the required cross section the surface shall be sprinkled with water from properly constructed sprinkling wagons and again rolled according to the method already described. The amount of water used shall be sufficient to wet the gravel but shall be put on in such quantity and manner as not to wet and soften the subgrade. Sprinkling and rolling shall be continued until the surface is thoroughly bonded.[1]

When completed the gravel surface, shoulders, side ditches, and side slopes shall be true to the grade and cross section shown on the plans and drawings.

The contract price per ton for gravel to be used in surfacing shall be full compensation for digging, screening, loading, spreading, harrowing, rolling, sprinkling, and hauling the gravel one-half mile or less. Stripping of gravel pits will be paid for at the contract price for excavation. The contract price for overhaul of gravel will be paid on all gravel hauled a distance greater than one-half mile.

[1] If the gravel contains clay of such quality that it causes the surface material to adhere to the wheels of the roller, the surface should be sanded with coarse sand. It is advisable also to finish the surface of a gravel road, built of gravel containing clay, with a coat of sand about one-half inch in thickness, before traffic is allowed upon it.

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